COMMENTARY FOR TEACHERS

SCIENCE

A PROCESS APPROACH

AAAS

SCIENCE—A PROCESS APPROACH

COMMENTARY FOR TEACHERS

AAAS/XEROX CORPORATION

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FOREWORD

The child learns about the world around him through the use of his five senses—sight, hearing, smell, taste, and touch. The training of these senses and the accurate use of words to describe his experiences should begin at the earliest steps in his education. As he develops, it is important that he learn to think as correctly as possible about these experiences. The object of helping him to do this is not to make a scientist of him, but to fit him to grow into his place as a citizen in the modern world and to make his adult life more interesting and enjoyable.

Good teachers have always done something of this, bringing specimens into the room, calling attention to snow and clouds, and so on. The purpose of this guide is not to add to their present duties, but to enable them to perform these duties more effectively. Simple materials and operations are described. So are the processes by which the pupils can be taught to think more clearly about them.

The importance of introducing children to science is a matter of deep concern to the American Association for the Advancement of Science. This Association, founded in 1848 with 461 charter members, now includes some 120,000. It is also a federation of many scientific societies. It has established a Commission on Science Education. This Commission, while interested in science education at all levels, gave its first attention to children from Kindergarten through Grade 6.

The *Commentary* and exercises have been prepared and tested by scientists working with experienced teachers under the direction of The Commission on Science Education, set up by the American Association for the Advancement of Science. The work was supported by a grant from the National Science Foundation.

Paul B. Sears
Chairman of the Commission on
Science Education, 1962-1966.

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TO THE TEACHER

This *Commentary* is addressed to you who are teaching *Science—A Process Approach.* It has been written to help you teach science to elementary school children and should be used as a guide and as a reference. It is intended to be used by you as an individualized instructional instrument. It is for you to read, to study, and to enjoy.

First, read the *Foreword* and the *Statement of Purposes and Objectives of Science Education in School.* These sections will tell you what scientists think science in elementary school should be. They reflect the spirit of modern science and tell you why the program was developed. Next, read *Teaching Science—A Process Approach—Some Questions and Answers.* This section will answer questions you may have about the program and how you should teach it.

Psychological Issues

Psychological issues basic to the development of the program are treated in the sections on Psychological Issues, on Evaluation, and on Behavioral Objectives, Action Words, and Process Hierarchies. As you teach the program and test to see if your children are achieving the objectives of the program, you may want to read these sections several times.

The Process Exercises

A major part of this *Commentary* is devoted to the science process exercises, one on each of the eight basic processes and one on each of the five integrated processes. The organization of the process exercises is patterned after the organization of the exercises for children. These exercises start with a statement of behavioral objectives, and they include a rationale, several activities, and a self-evaluation. Before you teach your first exercise in any one of the processes, you will probably want to study carefully the *Commentary* exercise on that process and, if time permits, to work through the activities. You might, in any case, see how well you can answer the Self-Evaluation questions at the end of the exercise. If you can answer all of them satisfactorily, a reading rather than a study of the exercise may be sufficient.

In many respects, the thirteen process exercises will be the most useful and important part of the *Commentary* for you. You will enjoy working through these exercises, and in so doing, you will acquire a confidence in your own ability to use the processes of science that will enhance your enjoyment of science teaching.

Overview of Science Concepts and Science Background Papers

Science—A Process Approach is designed to present instruction that is intellectually stimulating and scientifically authentic. The program is based on the belief that an understanding of the scientific approach to knowledge of man's world has a fundamental importance as a part of the general education of every child. Children acquire this understanding by using the processes of science in learning science concepts.

The coverage of science fields is broad. Mathematics topics are included, to be used when needed as preparation for other science activities. Some of the exercises draw from the behavioral and social sciences. Most involve principles in physics, biology, and chemistry with a lesser representation of the earth sciences and astronomy. Information on content coverage of the total program is given in the section, *Overview of Concepts.* This section is then followed by 18 papers providing background information on science concepts that are covered in one or more of the seven Parts of the program. For example, if you are to teach an exercise in which the children explore situations involving forces, you will want to study the background paper on *Forces and Pressure.* You may also want to read through all of the papers in order to refresh and extend your own knowledge of science.

Index of Terms

Finally, the *Index of Terms* is for reference. For example, in an investigation the children may be producing carbon dioxide. You want to know whether that term has been used before, and in what circumstances. You want to know in what context they will learn more about carbon dioxide later. The *Index of Terms* will help you obtain this information.

PART 1: BACKGROUND MATERIAL

STATEMENT OF PURPOSES AND OBJECTIVES OF SCIENCE EDUCATION IN SCHOOL*

There is joy in the search for knowledge; there is excitement in seeing, however limited, into the workings of the physical and biological world; there is intellectual power to be gained in learning the scientist's approach to the solution of human problems. The first task and central purpose of science education is to awaken in the child, whether or not he will become a professional scientist, a sense of the joy, the excitement, and the intellectual power of science. Education in science, like education in letters and the arts, will enlarge the child's appreciation of his world; it will also lead him to a better understanding of the range and limits of man's control over nature.

Science as Enquiry

Science is best taught as a procedure of enquiry. Just as reading is a fundamental instrument for exploring whatever may be written, so science is a fundamental instrument for exploring whatever may be tested by observation and experiment. Science is more than a body of facts, a collection of principles, and a set of machines for measurement; it is a structured and directed way of asking and answering questions. It is no mean pedagogical feat to teach a child the facts of science and technology; it is a pedagogical triumph to teach him these facts in their relation to the procedures of scientific enquiry. And the intellectual gain is far greater than the child's ability to conduct a chemical experiment or to discover some of the characteristics of static

*This *Statement of Purposes and Objectives of Science Education in School* was prepared by Professor William Kessen of Yale University with the assistance of a panel of consultants and suggestions from the Commission. The statement was prepared to guide writers and teachers of *Science—A Process Approach,* and copies may be obtained by other persons and groups interested in the improvement of science education.

Members of the panel of consultants are:

Donald R. Coates, Harpur College
Margaret W. Efraemson, Public Schools, Philadelphia
Earl D. Hanson, Wesleyan University
Willard Jacobson, Teachers College, Columbia University
Jacqueline Mallinson, Western Michigan University
Guenter Schwarz, Florida State University

electricity. The procedures of scientific enquiry, learned not as a canon of rules but as ways of finding answers, can be applied without limit. The well-taught child will approach human behavior and social structure and the claims of authority with the same spirit of alert skepticism that he adopts toward scientific theories. It is here that the future citizen who will not become a scientist will learn that science is not memory or magic but rather a disciplined form of human curiosity.

The Scientific Attitude

The willingness to wait for a conclusive answer—the skepticism that requires intellectual restraint and the maintenance of doubt—is often times difficult for adult and child alike. The discipline of scientific enquiry demands respect for the work of the past together with a willingness to question the claims of authority. The attitude of intelligent caution, the restraint of commitment, the belief that difficult problems are always susceptible to scientific analysis, and the courage to maintain doubt will be learned best by the child who is given an honest opportunity to try his hand at scientific enquiry. With his successes will come an optimistic appreciation of the strength of enquiry; with his failures will come an understanding of the variety and challenge of our ignorance. For the scientist, child and adult, novelty is permanent; scientific enquiry continually builds novelty into a coherent design, full of promise, always tentative, that tames our terror and satisfies for a while the human desire for simplicity.

The Procedures of Science

Scientific problems arise in the life of children just as they arise in the guided exploration of scientists. Astonishment in the presence of natural beauty, surprise—even frustration—at the failure of a prediction, and the demand for sense in the face of confusion are the beginnings of scientific enquiry. But how do we then proceed?

Among the most demanding of scientific tasks and certainly among the most difficult to teach is the *statement* of a problem. Is there a meaningful question to be asked? What techniques should be used to answer it? How does one go about making a prediction or developing a hypothesis? As he asks these questions, the student begins to learn how active enquiry can lead to testable questions and eventually to the solution of problems. He is introduced also to the pleasures and problems of inventive thought—of considering what might be as well as what is.

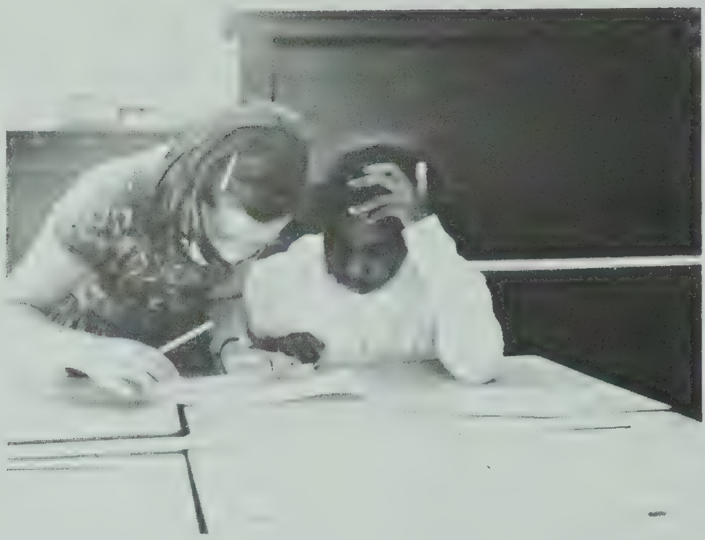
There are many ways to answer a provocative question in science and the child should come to recognize that he must adapt his method to the problem in hand. As he runs against different problems, the child will learn to use several *sources of reliable information*—observation, experiment, books, museums, and informed adults.

Whatever the problem, the child's *ability to observe* should be extended so that he understands the wide range of observations possible even when simple phenomena are under study. He must learn to order the evidence of his senses.

Attention to the complex activity of *comparison of phenomena* will introduce the child to an essential task in science—the perception of differences and similarities among events.

The child will use his ability to observe and to compare in building *systems of classification* and in recognizing their usefulness and their limitations in science.

The child should learn to use the *instruments of science.* As he studies these instruments, the teacher is given an opportunity to instruct the child in *measurement.* He will learn when it is wise to estimate a measurement and when precision is required; he will learn the importance of agreement among observers and the relations among different systems of measurement.



The use of laboratory techniques—especially the *experiment*—deserves special attention. The experiment is the sharpest tool of science and in devising an experiment the child exercises his ability to pose a question, to consider possible answers, to select appropriate instruments, to make careful measurements, and to be aware of sources of error. It is unlikely that children in the first years of school will manage well all aspects of sound laboratory procedure but the best lessons of the experiment can be taught only to the child who is actively engaged with the equipment and procedures of the laboratory. The teacher must adapt his desire for precision to the child's excitement in the search; a premature demand for exactness in experimental manipulation may blunt the student's commitment and pleasure.

After the problem is posed, the data gathered, and a hypothesis developed, the science student must *evaluate evidence and draw conclusions.* Sometimes this is a simple step; sometimes it involves the review and modification of the entire plan with renewed attention to problem, to hypothesis, and to data-protocols. The goal is to make sense of the data and the pursuit of this goal will, on occasion, lead to the detection of an error or to the design of another study. It may also lead to the *invention of a model or theory* through which we can comprehend data.

Throughout the course of science education the need to communicate is present. Describing a bird to his class, graphing a mathematical function, writing an experimental paper—experience with each mode of report is essential to the development of the science student.

The child's ability to communicate in science will both depend on and contribute to the solution of this most general problem of the curriculum—accurate and effective communication.

The procedures of science described here in the context of early science education are recognizably the procedures of science at all levels of sophistication. Scientific enquiry is a seamless fabric. The content will change, the demand for precision will vary, the generality of conclusion will be different, the interrelation of studies will be understood in different ways; but the procedures and attitudes of scientific study remain remarkably the same from the time the kindergarten child wonders about color to the time the graduate physicist wonders about particle emission.

Scientific Knowledge

The facts and principles of science change with each advance in our understanding of the world. For this reason, it is difficult to forecast with precision what scientific content the child should

know. Nonetheless, it is possible to sketch in outline the scientific knowledge that the properly educated child will possess within the first years of school. A knowledge of the basic findings of centuries of scientific enquiry gives boundaries and direction to the child's active exploration of his world. Under the governing premise that the curriculum in science must be defined by the child's growing comprehension of nature's order and beauty more than by the conventional categories of scientific knowledge, the child should know as much as he can actively seize about—

the universe; its galaxies, our solar system, the earth, and his immediate environment; the range of measurements used to describe astronomical and geological phenomena;

the structure and properties of matter; elements and compounds, chemical reactions and changes in properties, atoms and molecules, electrons, protons, and neutrons;

the conservation and transformation of energy; the electro-magnetic spectrum, energy of motion and potential energy, electrical energy and chemical energy; force and work, gravitational and magnetic fields;

the interaction between living things and their environment; animal and human behavior, the relation between biological structure and function, reproduction, development, genetics, evolution, and the biological units—cell, organism, and population.

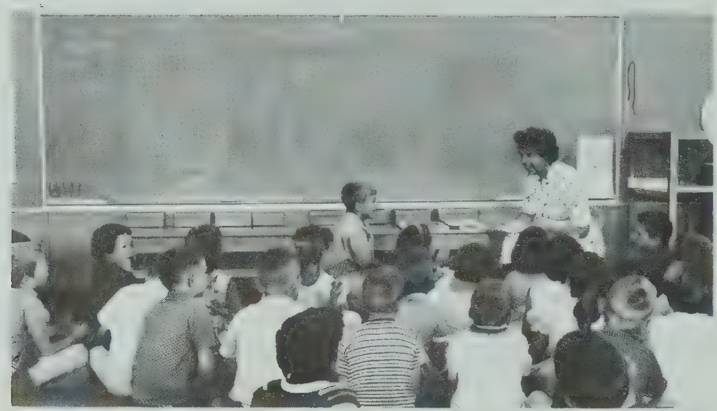
Science cannot be divided easily into labeled categories without loss. An emphasis on scientific principles that bridge the conventional subject-matter division will improve and simplify the teaching of science, making it more easily understood and more productive of meaningful problems for the child's own enquiry.

The Place of Science in the School Curriculum

Scientific enquiry, moreover, is partner and peer of the traditional divisions of study; decisions about education in science must always be made with consideration of the relation of science to the child's other studies. Levers and poems, energy exchange and historical analysis, genetics and geography—all present to the child an opportunity to extend his reach into the world; and in their different ways, all present to the child an opportunity to see beauty.

The Child and the Teacher

Rising above any statement of objectives for education is an irreducible fact: teaching is an exchange between people. This simple human fact is both problem and promise for education in science as it is for all education. The child can understand only what he has been prepared to understand; the teacher can teach only what he knows; and the meeting of the prepared child with the skillful teacher is an unforgettable encounter for them both. In the successful educational encounter, the child will become an active searcher for knowledge and the teacher will form attitudes toward enquiry as well as offer information about the world. The related and intricate problems of teacher training and the nature of learning are closely intertwined with the goals of science education. Science, rooted in man's curiosity and love of order, is called to its full humanity by the child's desire to know.



TEACHING *SCIENCE—A PROCESS APPROACH* SOME QUESTIONS AND ANSWERS

How Did *Science—A Process Approach* Come About?

Since the mid-fifties, revolutionary changes have been taking place in the teaching of science. Teams of scientists and teachers have attempted to bring about far-reaching improvements in science education at all levels, including the elementary school level. Believing that experience with science must begin with the learning of language and continue throughout the educational process, the Commission on Science Education of the American Association for the Advancement of Science, with financial support from the National Science Foundation, embarked upon the preparation of a science program for kindergarten through grade six. Materials were first written in the summer of 1963 and in each of the following summers through 1967. During each school year, beginning with 1963-64, the materials were taught in tryout centers across the country. Feedback information from the tryout teachers and systematic evaluation of the children's competencies after each exercise were used as the basis for revising and rewriting the materials during each succeeding summer writing session.

What are the Outstanding Differences Between This Curriculum and the More Traditional Elementary Science Curricula?

There are three particularly significant differences.

First, traditional programs in science consist of more or less separate units in which the children learn something about spiders, or magnets, or planets, or simple machines, or birds, or many other things. By the end of a school year, a child has learned a number of facts about the world of science. This type of program assumes that science is mostly a collection of facts and concepts about the natural world. In contrast, *Science — A Process Approach* assumes that science is what scientists do.

Science—A Process Approach makes the assumption that science is more than an encyclopedic collection of facts, and that children, even in the primary grades, will derive more from the study of science if they learn the behaviors of scientists. Although these are complex, they have been classified into a number of process skills, some simple and some more complex, and the processes form the core of the program. In learning to do what scientists do, the children become highly involved in using the processes of science.

For the primary grades, the exercises in the program stress the following basic process skills:

Observing	Measuring
Using Space/Time Relationships	Communicating
Classifying	Predicting
Using Numbers	Inferring

These basic processes provide the foundation for the more complex or integrated processes which are emphasized in the intermediate grades. The integrated processes are these:

Controlling Variables	Defining Operationally
Interpreting Data	Experimenting
Formulating Hypotheses	

A second difference is that in *Science—A Process Approach,* the ability to read is not so essential as it is in many traditional curricula. Thus, inquiry into science can begin as early as kindergarten. Success does not depend on skill in reading but on the ability to use the processes of science. This difference has important implications. For example, it means that children from low socioeconomic backgrounds, many of whom have reading problems, can and *do* have the same opportunity for success as those from higher socioeconomic strata. It also means that the nonverbal child can demonstrate his knowledge and skill by doing something with materials, rather than having to talk about it coherently.

Third, *Science—A Process Approach* has been field-tested in schools located throughout the country. The tryout centers were chosen to provide a variety of geographic areas and ethnic groups, variety in socioeconomic background levels, variety of school locations—that is, inner-city, urban, suburban, and rural—and variety in the experience of the teachers involved. Four experimental editions have been used, each edition revised on the basis of feedback information from the teachers who have taught the curriculum. The material for this program has constantly been assessed and revised. The tryout centers are listed on page 13.

Is There a Textbook or Other Reading Material for the Pupil?

Most of the materials have been prepared for the teacher only. Rather than reading about science, in this curriculum, children learn science through the use of their senses, mental involvement, and direct manipulation of objects in their immediate environment. Of course, some children want to know more about topics they investigate. Reading about science and scientists is an important supplement to a child's investigations. You should, of course, encourage further reading.

In Parts E, F, and G, the activities begin to include the use of *Data Sheets* which requires some reading and writing ability. At first, the *Data Sheets* are very specific in their directions and structure. Later, the children are expected to be able to design their own sheets in an appropriate form.

Also, in Parts F and G, reading exercises and tests are included. These consist of brief accounts of experiments which have been reported in scientific journals. The accounts have been rewritten in words the children can readily understand. After they have read the account, they are asked to identify one or more of these elements: the hypothesis being tested, the variable that was manipulated, which variable responded, which variables were held constant, and how the data were interpreted—that is, whether or not the hypothesis was supported. In preparing their answers, the children may refer any number of times to the original account.

How Will the Process Approach Help a Child in His Education?

Scientific knowledge is increasing so rapidly that it is impossible for scientists themselves to keep up-to-date in all sciences. It is likewise impossible for pupils to learn everything. One strategy is to equip each child with skills he can use to find solutions to scientific or other problems he may encounter in the future. *Science—A Process Approach* aims to equip each child with competence in the processes of science. Through your instruction, you will be providing children with an opportunity to practice *a way of defining and solving problems.*

Children will become citizens and consumers in a society increasingly influenced by scientific and technological progress. Competence in the processes of science will help them to exercise good judgment as adults in such a society. They will have gained habits applicable to effective functioning in many roles of living if they can observe, classify, and measure carefully; if they can formulate hypotheses to explain their observations and measurements; if they can test their inferences and hypotheses and interpret their data.

What is the Place of the Content (Facts) of Science in This Process-Oriented Program?

Certainly you cannot teach scientific processes without using some content. Much science content is included in *Science—A Process Approach,* but the emphasis is on the processes. In order to attain competence in the processes of science, children deal with such topics as plants, animals, energy, light, temperature, heat, solids, liquids, gases, life cycles, electricity, magnetic fields, motion, falling bodies, forces, the sun's motion, and many others. The children become very interested in and curious about the topic they are studying even though the primary objective of the instruction is for them to acquire new competencies in the processes of science. Many will pursue their aroused interest through additional tests and investigations and through reading.

For specific detail about the content of these materials, see the section of this *Commentary, Overview of Content.*

In What Ways Can the Development of *Science—A Process Approach* be Considered an Educational Experiment?

The development of *Science—A Process Approach* and its tryout in the schools has been a major experiment in education. Two significant innovations of this particular experiment are:

1. The clear identification of the objectives and activities of each exercise with one or more of the processes of science
2. The provision for evaluation which has been built in from the beginning and revised where necessary after each tryout

These two important features of the program are described in detail in the section on *Evaluation* which begins on page 19.

Other experimental aspects of *Science—A Process Approach* are:

1. The inclusion of topics seldom if ever included in elementary science programs. The exercises on color and exercises from the behavioral sciences are two examples of such topics
2. The provision of exercises usually reserved for the mathematics program which enable the teacher to emphasize quantitative aspects of science experiences earlier than is possible in traditional science programs
3. The development of a working team of scientists from the several disciplines of science and of administrators and teachers from the schools

The team effort which has resulted in the development and use of *Science—A Process Approach*

illustrates what may be achieved by a group of scientists and teachers working together over a period of several years. Nearly 500 persons have been involved as members of the research team which has developed and tested these materials.

How Successful Was *Science—A Process Approach* During its Experimental Tryout?

An extensive evaluation was an integral part of the development of this curriculum, and revisions of the exercises were based on the evaluation data. Schools in twenty-two school systems served as tryout centers and were sources of feedback information on the experimental materials. On the basis of the suggestions of the tryout teachers and the competency tests of the children, each exercise was revised until its objectives could be acquired by most of the children in the tryout classes.

The goal set for *Science—A Process Approach* was that 90% of the children should acquire a mean of 90% of the behaviors of each exercise. In the third year of tryout, 68 of the 102 exercises which are included in Parts A-D met the *90-90* standard of success. Twenty more satisfied the *80-90* standard; that is, for these exercises, 80% of the children acquired 90% of the desired behaviors. Eleven of the remaining exercises met the *70-90* standard, and only three were below that level. The final revision of the exercises, prior to their publication and general release, should have further improved those exercises which did not meet the top standard.

The data just given apply to those children who had the optimum preparation in the program. In the third year of tryout, no child could have had more than two previous years in the program. Thus, the data for Part D, while still quite favorable, were not based on optimum preparation. However, on the basis of the tryout data, you can expect that most children in kindergarten and grades one to three will acquire 90% of the desired behaviors.

For Parts E, F, and G, the tryout data were useful for revising and rewriting the materials, but less confidence can be placed in them as genuine indications of expectations for pupils who come through the entire program. Even so, the third-year tryout data for children who have had three years of *Science—A Process Approach* show that 57 of the 82 exercises in the three Parts meet the *90-90* or *80-90* standards (32 and 25, respectively), leaving 25 exercises in the lower categories. Revisions of these Parts for the final published materials should improve these results, especially for pupils with more years of experience in the program. (For further discussion of the evaluation of the program, see the section on *Evaluation.*)

If I Teach *Science—A Process Approach*, I Teach Only One Part. How Well Do I Need to Know the Other Parts of the Program?

The more you know about the whole program, the better able you will be to fit your teaching into what has preceded and what will follow for the children. You will find in the exercises you are teaching numerous references to experiences the children have had, or should have had, in previous years. The essential skill prerequisites are indicated in the sequence charts and in the Hierarchy Chart. Your most immediate needs will be to know these prerequisites.

Beyond satisfying these urgent needs for your teaching, you will find it helpful and interesting to read through the instructional booklets of all of the Parts preceding the one you are teaching, and probably also those that follow.

Is the Process Approach Intended for a Certain Type of Learner, Such as a Bright Child?

No, the program is intended for use in teaching science to any and all children. In the experimental tryout, teachers in all kinds of schools, in all kinds of areas, reported successful experiences with *Science—A Process Approach.* For example, here are some typical comparative data, for

Parts A-D taken from the data given by Walbesser in the second report on the evaluation model (1968), referred to on page 20 of this *Commentary.*

First exercise in	Percentage of children who acquired 90% of the specified behaviors	
	All classrooms	Classrooms in low socioeconomic areas
Part A	97	96
Part B	81	81
Part C	87	94
Part D	90	90

These data show that children in disadvantaged areas, where reading ability may be a function of background as well as aptitude, can perform as successfully as any others in an activity oriented program. Of course, variations exist among classes and among schools. But the universal potential of this program for all kinds of learners has been demonstrated.

Where Were the Tryout Centers Located?

Beginning in the fall of 1963 and continuing for five years, experimental editions of exercises in all Parts of *Science—A Process Approach* were extensively tried out in schools. Most of the exercises were tried out in three experimental versions, some in four, and a few in five. The tryout centers, varying in number from eleven to fifteen each year, were selected by the Commission on Science Education. The centers chose the tryout teachers.

The school systems that, as tryout centers, gave this important assistance in the development of *Science—A Process Approach* were:

Arizona

- Tucson

California

- Berkeley
- Kern County
- Palo Alto

Florida

- Tallahassee

Illinois

- Glencoe
- Monmouth
- University of Chicago Laboratory Schools

New York

- Ithaca
- Manhasset
- Pelham

Ohio

- Lakewood

Oregon

- Eugene
- Portland

Pennsylvania

- Philadelphia

(continued on next page)

Kansas

Overland Park

Maryland

Baltimore City

Massachusetts

Lincoln

Texas

Austin

Washington

Seattle

Wisconsin

Omro
Oshkosh

Some school systems served as centers throughout the full five-year tryout period and the others for any number from one to four years.

Associated with each center were a center coordinator and science consultant, sometimes the same person and sometimes two persons. The number of tryout teachers varied from three to sixteen from center to center and year to year. The Commission provided the school system with all needed teaching materials and a small stipend for each tryout teacher, consultant, and coordinator. Regularly scheduled inservice classes were held in each center. The teachers provided extensive feedback information, exercise by exercise. The feedback data and how they were used are described in some detail in the publication, *An Evaluation Model and Its Application.*

Is *Science—A Process Approach* Intended for a Certain Type of Teacher?

During the experimental tryout of this curriculum, there was great variation in the backgrounds of the teachers. Some teachers had no college science or mathematics. Some teachers had as many as seventy-five units of college biology. Some teachers had not taught previously. Some teachers had taught for over forty years. Yet, there was little if any correlation between these characteristics of the tryout teachers and their success in teaching the exercises.

Evaluation of the teacher education program has shown that successful teaching of this curriculum, as measured by performance of the children, depends upon the teacher's own competence in the science processes. For this reason, the *Commentary for Teachers* requires you to be a participant as you learn about *Observing, Classifying,* and the other processes. Individual demonstration of competence.is an essential part of the teacher education program.

Will I Have to Change the Way I Teach?

If you have been helping children learn for themselves, you will find that *Science—A Process Approach* has been designed for you. The greatest difficulty in teaching these process materials is not so likely to lie in keeping the class work pupil centered as it is in remembering that the chief objective is not to teach content but to teach process. For example, as children are observing an expanding balloon for the purpose of learning how to communicate, you must refrain from becoming concerned that each child knows what caused the balloon to increase in size. You must focus your attention on how well each child is able to communicate what changes he has observed. You constantly will have to guard against the tendency to emphasize facts rather than process.

For many of us, teaching has meant telling and showing. The science classes most of us have known, either as students or teachers, have more often been characterized by lectures and discussions about the facts of science than on practice in the methods of science. Unless you have had the opportunity to conduct a personal investigation into some problem in science, hower small, you may at first find it difficult to hold back while children plan to carry out an investigation.

If teaching in this way is new to you, you can look forward to a very exciting and rewarding time in the classroom—if you are willing to give it a try.

What Kind of Classroom is Required for Teaching *Science—A Process Approach?*

During the years when these materials were being evaluated, many different types of classrooms were used. They varied from the traditional room with fixed desks, limited floor space, and no storage shelves, to the most modern room with movable furniture, large floor spaces, and adequate storage facilities. One tryout school had a science laboratory. There is no evidence that the achievement of competence in the processes was affected by the classroom facility. But there can be no question that the conscientious teacher of *Science—A Process Approach* faces fewer problems if adequate floor space, storage and shelf space, and movable furniture are available.

Since this curriculum stresses active participation by children, each child should have many opportunities to handle materials, to demonstrate the use of simple equipment, and to construct tests of his ideas. This emphasis on providing individual or small group practice raises problems of logistics for the teacher.

No single permanent arrangement of the classroom will meet the learning needs of the children for all activities. Space requirements for group work change from day to day. Sometimes, maximum clear floor areas are required; at other times, the whole class will need to be able to observe clearly a single operation and discuss it; most frequently, small groups will be busy at work stations spaced as far apart as possible. You will need to plan for this flexibility.

The Xerox laboratory materials come in sets of movable drawers which provide the storage space for supplied and accumulated materials for an exercise. In addition to the space for these drawers, adequate shelf, display, and tray space is essential for the children to keep their materials. Old cafeteria trays, cottage cheese cartons, and other common materials can be used in many ways for individual storage.

How Do I Obtain Equipment and Supplies Necessary to Teach *Science—A Process Approach?*

Although some materials will be found among the usual school supplies, and others may be purchased locally, most of the equipment and supplies are provided in the kits prepared for each of the exercises. The kits and exercises are available from the same supplier, Xerox Corporation, 191 Spring St., Lexington, Massachusetts 02173

Can Instructional Strategies in *Science—A Process Approach* be Used with Other Curriculum Areas?

They can and should be. Many opportunities exist to use the science exercises as motivation for reading, oral and written communication, mathematics, art, and social studies. The emphasis on the processes makes their application universal; their use is not and should not be limited to experiences in science. Many teachers who have used *Science—A Process Approach* have said that this curriculum has influenced them to change their objectives and instruction in other curriculum areas. Teachers have also reported that children become motivated to use their newly acquired science competencies, vocabulary, and science knowledge in art, social studies, communications, and in independent thinking and activity.

Why is there a Process on Using Numbers in this Science Curriculum?

Competence in using numbers is essential in science. Because using numbers cannot be separated from the study of science, *Science—A Process Approach* includes development of those mathe-

matical competencies necessary for a child to function in the program. A complete curriculum in mathematics is not included, nor was it intended. However, even if your children have experience with the competencies in the *Using Numbers* process prior to the exercises in which these competencies are needed, the exercises may provide a second frame of reference.

Are Tests for the Evaluation of Pupil Achievement Available?

You may use two different measures to assess pupil achievement. For each exercise in Parts A through D, there is an *Appraisal* activity and an *Individual Competency Measure.* For exercises in Parts E, F, and G, the appraisal has been dropped, but a *Group Competency Measure* has been added so that both it and the *Individual Competency Measures* are available.

The *Appraisal* is planned as a class activity. As you watch the class perform, you will be able to judge how the class as a whole appears to have achieved the objectives of the exercise. The *Group Competency Measure* takes advantage of the children's ability to read and enables you to judge the individual work of the whole class. The *Individual Competency Measure* is administered to individual children by the teacher or by a professionally prepared assistant. The purpose is to determine whether or not a child can perform the tasks specified by the objectives after having had the experiences provided by the exercise.

For more discussion of the use of these measures, see the section of this *Commentary* on *Evaluation,* page 19.

Is it Possible to Begin to Teach This Program in any Grade, or Must One Start in the Kindergarten?

The program has been designed to take advantage of cumulative learning. Because of the mobility of our population, many of you will have children in your class who will not have used the materials in previous years and may not have the competencies that are prerequisite for the exercise you are to teach. For this reason, the minimum prerequisites are identified in the sequence chart for each exercise. This chart refers to the activities in earlier exercises that should be reviewed and, if necessary, taught to ensure that the children possess the prerequisite process skills. You will be able to follow the sequence of exercises in the Part you are teaching by interweaving prerequisite activities into the sequence as needed.

You should expect that children who have been taught *Science—A Process Approach* in previous years will acquire a higher level of competence than children who are studying this program for the first time.

How Do I Know Which Part to Teach in My Grade?

In most cases, it would be safe to assume that Part A should be taught in kindergarten, Part B in first grade, and so on through the grades. However, if no kindergarten exists, then you would probably do better to work rapidly through Part A and into Part B for the first grade than to begin with Part B and teach selected prerequisites from Part A as needed. For any Part, if your class achieves competence in the objectives of the exercises before the school year is over, you should move on to the next Part. The term *Part* is used to designate sections of the program rather than grade because the order of the Parts is more important than the grade level. It is hoped that the Parts will not be equated with grade levels, but that there will be flexibility to meet the different needs of children and school communities.

Should I Present the Exercises in the Order in Which They Appear in the Parts?

The exercises in each Part have been ordered on the basis of complexity of behaviors which

the children are to acquire. The hierarchy for each science process, described in the *Description of the Program* booklet for each Part, illustrates the behavioral sequence. You are strongly advised to follow the sequence prescribed by the hierarchy, and this will usually mean that you should teach the exercises in the sequence in which they occur in the Parts.

Occasionally, you may have to deviate from the sequence because of conditions over which you have no control. When you do go on to an advanced exercise, return to the exercise you have omitted as soon as conditions permit.

How is Each Exercise Organized?

Each exercise has a process title and a subject title. The process title indicates how the exercise is classified and which process is to be emphasized in the exercise. Other processes may be introduced during the instruction, but the process to which the exercise belongs is primary. It should not become subordinate either to the content of the exercise or to other processes. The numeral in the process title identifies the level of the exercise in the process sequence, as for example, *Observing 2,* and *Using Numbers 5.*

The subject title is brief and descriptive; it often indicates the context in which the activities demonstrate the process, as for example, *Observing Animals* or *Describing Physical Changes.*

Each exercise is organized into these sections: *Objectives, Sequence, Rationale, Vocabulary, Materials, Instructional Procedure, Generalizing Experience, Appraisal,* and *Competency Measure.*

The *Objectives* are statements of what the children should be able to do at the completion of the exercise. The list represents the minimum behaviors to be acquired. The children can and will learn much more from the activities. The list of objectives, however, provides you with clear guides for instruction; it also provides the basis on which to assess whether or not the children have acquired the desired behaviors.

Of course, if the children can demonstrate the behaviors specified in the *Objectives* prior to your teaching the exercise, you should move ahead. If you think the children have already achieved the objectives, teach the *Appraisal;* if your prediction is confirmed, go on to the next exercise. If your prediction is not confirmed, then you should teach the exercise. Remember, in this curriculum, demonstrated performance is your indicator of what kind of instruction is needed.

The *Sequence* indicates the prerequisites for the exercise. It also identifies the later experiences that depend upon the exercise. It gives you an idea of how the exercise fits into the hierarchy for each process, and what skills from other processes are necessary for success in this exercise.

The *Rationale* contains a variety of useful background information. It may include a brief statement of how the exercise helps the development of process skills, and explanatory statements about the content of the exercise and its importance in science. It may include various kinds of advice about the materials you and the children will be handling in the activities. In many cases, it reflects the experience of other teachers who have taught the exercise.

The *Vocabulary* lists new words and phrases which are introduced in the exercise. After you have completed the exercise, your pupils should be able to respond to or use these words, but expect them to use the words freely only after they have had many experiences with the objects and ideas which the words name or describe.

The *Materials* section lists all of the equipment you will need to teach the exercise.

The *Instructional Procedure* is divided into an *Introduction* and several *Activities.* The *Introduction* should serve to arouse interest and get the children involved. It may give you clues about whether the children can perform any of the objectives prior to the instruction. It helps you decide what activities will need most emphasis. The amount of time required for each activity will depend upon the children's abilities, the kind of activity, and your own instructional strategy. Each activity describes how you and the pupils are to be involved in the instruction in the process approach.

Generally, the activities are arranged in the sequence which has been found to be most helpful for the development of the objectives. Since each activity illustrates one part of a planned progression, it should be taught in sequence unless otherwise indicated. In some exercises, alternative or optional activities are given. Use these as you see fit. Do not feel obliged to teach all of the activities if in your judgment the children have acquired the behaviors stated in the *Objectives.*

The *Generalizing Experience* provides an opportunity for the children to relate their newly acquired competencies to a new situation in a different context. It may be used to test the ability of the children to perform in a new situation, to challenge exceptional children, or simply as a summarizing activity.

The *Appraisal* is a planned class activity which helps you assess whether or not the children have acquired the behaviors prescribed by the objectives of the exercise. The children's performance provides you with an observable means for deciding whether or not to terminate the exercise.

The *Competency Measures* consist of test items which can be administered as specified to individual children or to the class as a whole (*Group Competency Measures,* Parts E, F, G). Each item of a *Competency Measure* is specifically related to the objectives of the exercise and uses different materials or context from those in the activities. Questions which might be answered from memory are avoided.

What Do I Need to Do to Prepare to Teach an Exercise?

As you would expect, advance preparation is essential. The tryout teachers of *Science—A Process Approach* suggest that you need to do the following things:

1. *Gather, prepare, and try out materials in advance*
2. *Appraise your own competence in the process emphasized by the exercise*
3. *Identify the action verb in each objective and demonstrate the expected behavior*
4. *Identify in which activity each objective is taught*
5. *Identify the position of the objectives of the exercise in the hierarchies*
6. *In your day-to-day preparations, make use of the children's performance and the children's suggestions*

EVALUATION IN *SCIENCE—A PROCESS APPROACH*

The strategy of evaluation built into *Science—A Process Approach* from its beginning is a most significant innovation. Extensive evaluation materials are an essential part of the program. Each exercise contains clearly stated objectives, phrased in terms of observable pupil behavior. Included in each exercise is the means for testing pupil achievement in relation to the stated objectives.

Figure 1 shows a summary of the overall evaluation strategy, described as a sequence of cells

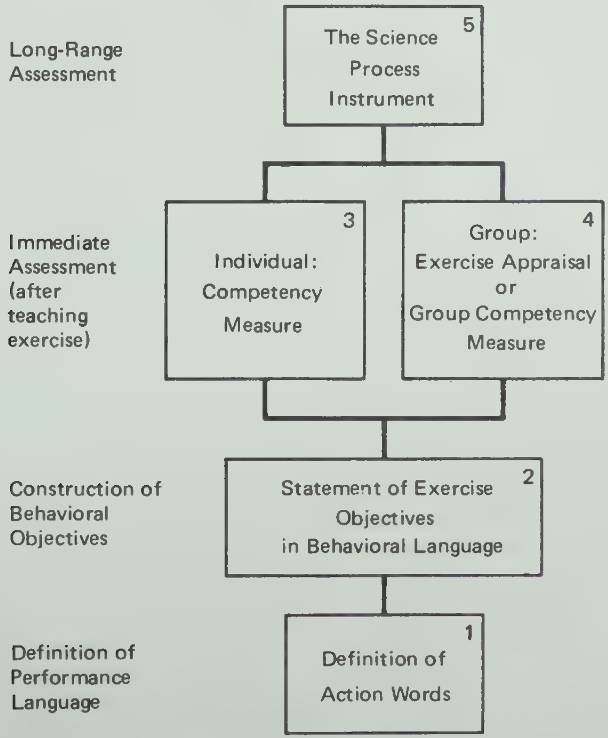


FIGURE 1

(rectangles) numbered from 1 through 5. Cells 3, 4, and 5 represent the evaluation instruments which test the achievement of the objectives of the program. In order to make entirely clear what performances are defined by the behavioral objectives (Cell 2), the action word in each objective is chosen from a list of nine carefully selected action words defined for use in this program (Cell 1).

In this brief discussion of evaluation, the instruments used will be described first (Section A). Then, Section B will treat the bases for the instruments—namely, the behavioral objectives, action words, and process hierarchies.

SECTION A

THE EVALUATION MATERIALS, THEIR NATURE AND PURPOSE

Immediate Evaluation Instruments

To help you determine whether a majority of the children in the class have satisfactorily attained the objectives of an exercise, an *Appraisal* is provided in each exercise in Parts A through D. This is a class activity designed to help you evaluate overall class performance in a general sense and to decide when the class has progressed sufficiently to move on to the next exercise.

Each exercise in Parts A through D also has an *Individual Competency Measure.* When this measure is administered, you (or another tester) can observe just what the child is able to do. He is expected to speak or perform in some way to demonstrate his learning. Therefore, the measurement of the child's achievement does not depend on what he is able to read. The tryout experience has indicated that this test is especially useful in helping to assess those pupils who are difficult to appraise.

Each exercise in Parts E and F and the first five exercises of Part G have both an *Individual* and a *Group Competency Measure.* There is no *Appraisal* in the exercises of these Parts. The *Group Competency Measures* have the advantage that they can be administered simultaneously to all of the children in a class. A child's achievement on the group tests will, of course, depend in part on his ability to read, and often in such a test, there is little opportunity to examine how a child handles equipment or plans and carries out an investigation.

Following the first five exercises in Part G which review the major behaviors of four of the integrated processes, there are fourteen exercises for the process of *Experimenting* nine of which have *Competency Measures.* The *Competency Measures* for those nine exercises are prepared to be administered as written tests for the class, but you can modify them if you wish to administer them to an individual. The final exercise in the *Experimenting* sequence serves as a competency measure for all exercises in the process of *Experimenting.*

In addition, in Parts F and G, short reading exercises are introduced. Some of these are designated as evaluation exercises. In a reading exercise, the child is given a modified version of a scientific report that appeared in the magazine, *Science.* The report has been rewritten in the vocabulary of fifth- and sixth-grade children. After the children have read the report, they are asked to interpret the account of the investigation. They identify the hypothesis the investigator was testing, the variables he controlled, the operational definitions he used; then they interpret the data in the report.

Initially, the immediate evaluation instruments, especially the competency measures, were designed to evaluate the curriculum in its developmental period. During the five years of tryout, the competency measures have been revised in each summer writing session. They are now prepared for use in any class in which *Science—A Process Approach* is taught. With the tests, you can easily see or hear how well the children have acquired skills in the processes of science.

Most of you will wish to make full use of the competency measures to evaluate the individual achievement of a child as well as the achievement of the class as a whole.

These instruments are useful also to administrators. In the administration of schools, curriculum evaluation is a major and continuing problem. The competency measures can supply school administrators with data which are pertinent to evaluating the success of the science curriculum in a grade, throughout a school, or on a system-wide basis.

Finally, the competency measure tasks which correspond to the specific performance objectives of an exercise can offer a valuable supplement to any teacher's preparation and a swift check on his understanding of the exercise and its aims. If *Science—A Process Approach* represents a substantial departure from your previous science teaching, this use of the competency measure may be especially significant for you.

Long Range Assessment

The overall evaluation strategy of *Science—A Process Approach* included plans for the development of a *Science Process Instrument* to appraise the long-range achievement of process goals. This instrument was to be designed to assess pupil capabilities in all the basic and integrated science processes identified by the curriculum.

With the behavioral hierarchies (see Section B) as a guide, seven process measures, in experimental edition, have been developed for the eight basic processes, one for each process except *Communicating* and *Predicting,* which are combined in a single test. Thus, process measures have been prepared for *Observing, Using Space-Time Relationships, Classifying, Using Numbers, Measuring, Communicating and Predicting,* and *Inferring.* The total testing time required for administering these seven tests to an individual child is estimated to be two to four hours. The results of the test may provide an inventory of the individual child's achievement in the process skills.

Experimental editions of the seven tests of the *Science Process Instrument* for the basic processes are available from AAAS. Time and support funds have not been available for validation of the tests. Copies are to be sold to educational researchers in school systems and colleges and universities with the hope that they may wish to provide validation of the experimental editions or validation of modifications of these editions. Copies will also be made available to school systems that may wish to use the tests in placing children who enter the program late, or for use with classes that start the program with Part D, for example. Each item in the *Science Process Instrument* corresponds to a cell on the hierarchy chart. Thus, a profile for each child could be made, using the *Science Process Instrument* and the hierarchy chart. However, schools that use the *Science Process Instrument* in this way must recognize that the tests have not yet been fully validated.

The *Science Process Instrument* for the integrated processes is not complete enough for experimental use. Educational researchers are encouraged to develop an integrated processes instrument using the *Science Process Instrument* for the basic processes as a model.

SECTION B

BEHAVIORAL OBJECTIVES, ACTION WORDS, AND PROCESS HIERARCHIES

Behavioral Objectives

Each exercise in the seven Parts of *Science—A Process Approach* begins with a clear statement of objectives, expressed in terms of children's performances. The objectives are statements of what an individual child is expected to be able to do after successful completion of the exercise.

In this sense, the objectives are properly called *behavioral* (or performance) *objectives.* The successful attainment of an objective can be demonstrated by having the child do specific things which you (or another observer) can observe.

Some examples of behavioral objectives from *Science—A Process Approach* are:

The child should be able to IDENTIFY the following three-dimensional shapes: sphere, cube, cylinder, pyramid, and cone.
The child should be able to IDENTIFY and NAME numbers in the sequence 11 through 99 as successors of ten, twenty, thirty, and so on.
The child should be able to DISTINGUISH between statements that are observations and those that are explanations of observations, and IDENTIFY the explanations as inferences.
The child should be able to CONSTRUCT an inference to explain the movement of liquid out of an inverted container when air moves into it.
The child should be able to DESCRIBE and DEMONSTRATE that the farther an object is located from the center of a revolving disc, the greater is its linear speed, although its rate of revolution is the same.
The child should be able to CONSTRUCT predictions from a graph about water loss from plants over a given period of time.

Compare these objectives with the following list sometimes found in elementary science curriculum guides:

The purpose is to study the lines of force in a magnetic field around two bar magnets.
The learner will see the necessity for using experimental methods on the measurement of physical phenomena.
The purpose is to investigate the relationship of mass and weight.
The child will realize the value of organizing observations.
The child will develop an understanding of the properties of liquids.

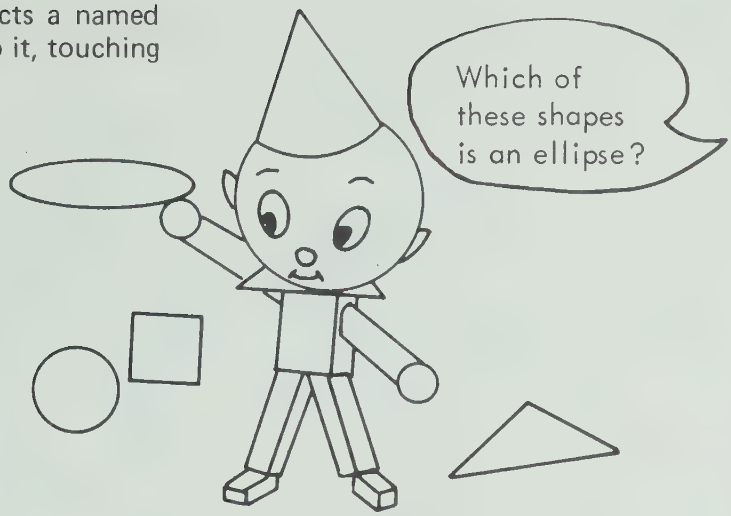
These objectives do not describe an observable performance of the child. For example, what does the child do to show that he is able to *see the necessity for* or *realize the value of?* If the achievement of these objectives is to be observed and measured, then additional definition of these phrases is necessary.

Science—A Process Approach has adhered rigorously to the goal of expressing its objectives in behavioral terms. In order that the behaviors described in the objectives of *Science—A Process Approach* will be interpreted in the same way by all who use them, the number of action words used in the objectives has been limited to nine, and these nine words have been carefully defined. As you plan to teach an exercise, you may wish to refer to the definitions and examples in the next section.

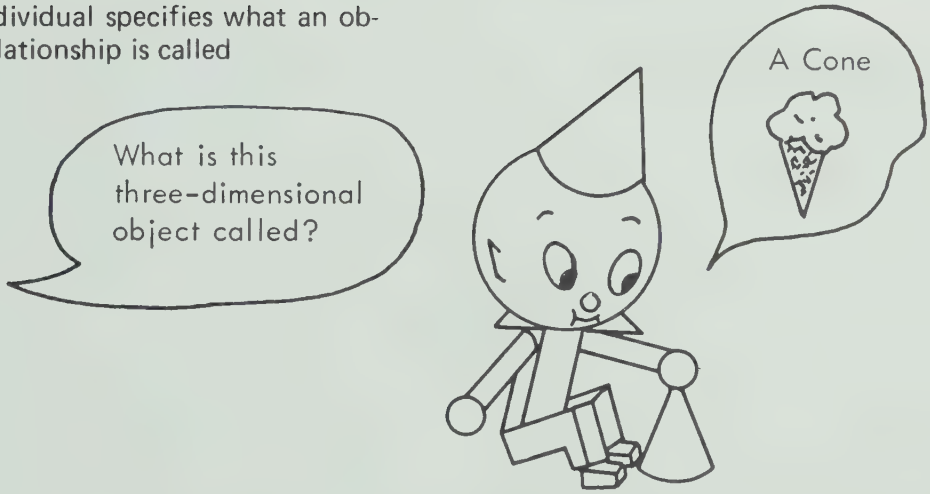
Action Words: Definitions and Examples

These are the definitions of the action words which name the performances specified in the objectives of *Science—A Process Approach.*

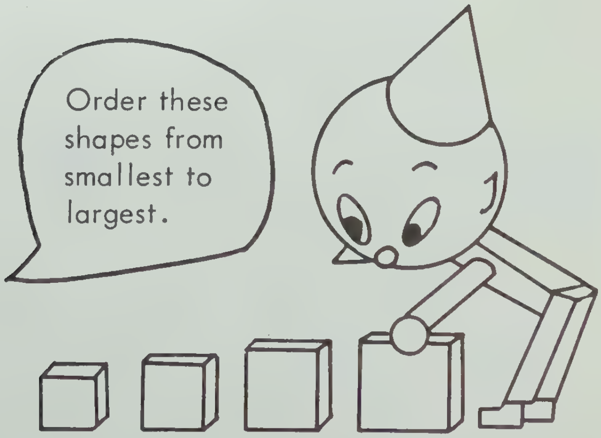
IDENTIFY The individual selects a named or described object by pointing to it, touching it, or picking it up



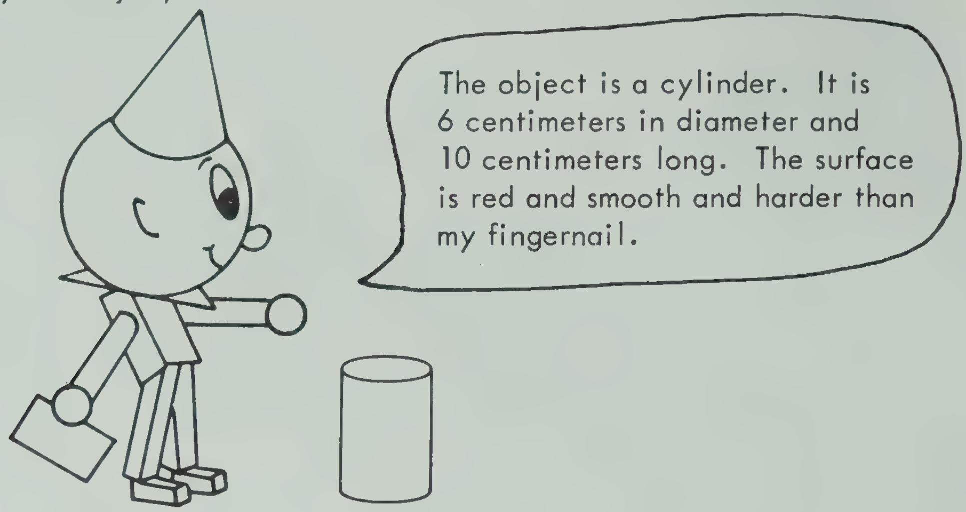
NAME The individual specifies what an object, event, or relationship is called



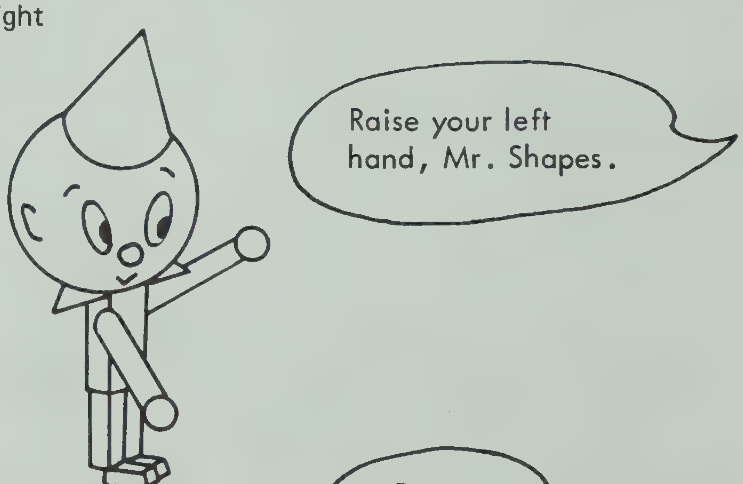
ORDER The individual arranges three or more objects or events in a sequence based on some stated property



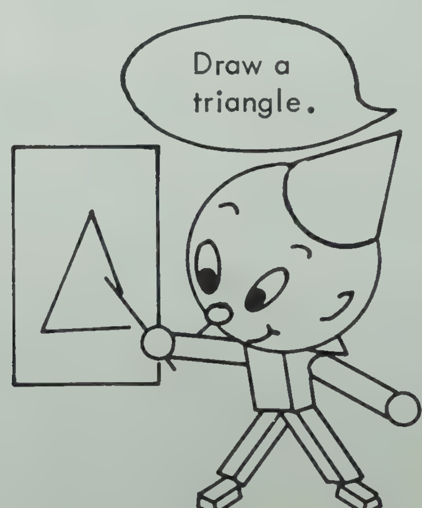
DESCRIBE The individual states observable properties sufficient to identify an object, event, or relationship



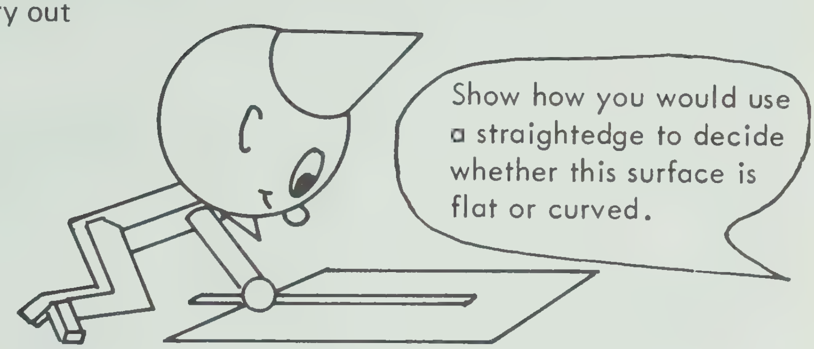
DISTINGUISH The individual selects an object or event from two or more which might be confused



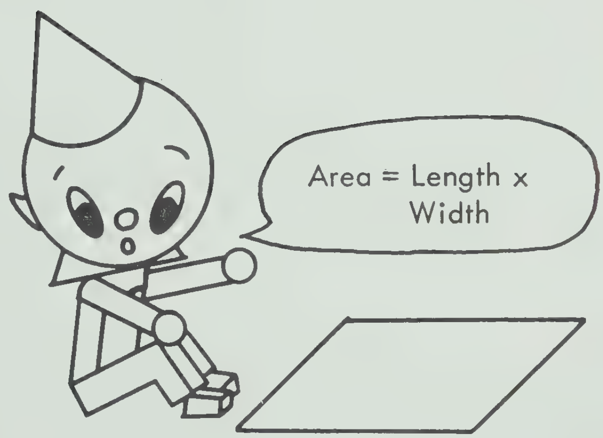
CONSTRUCT The individual makes a physical object, a drawing, or a written or verbal statement (such as an inference, a hypothesis, or a test of any of these)



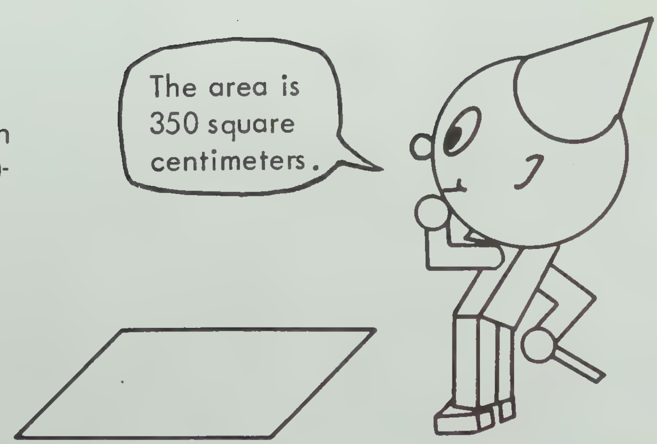
DEMONSTRATE The individual performs a sequence of operations necessary to carry out a specified instruction



STATE A RULE The individual communicates verbally or in writing a relationship or principle that could be used to solve a problem or perform a task



APPLY A RULE The individual derives an answer to a problem by using a stated relationship or principle



If you feel the need for further assistance in interpreting the action words or in using the behavioral objectives see the *Guide for Inservice Instruction* and the associated *Response Sheets.*

Hierarchies

Each exercise of *Science—A Process Approach* has a focus toward one of the *process hierarchies* and, to identify that focus, carries a process label, a process number, and a subject title. For example,

Observing 3, Observing Temperature
Using Space/Time Relationships 9, Shadows
Classifying 8, The Color Wheel—An Order Arrangement
Predicting 4, The Suffocating Candle
Defining Operationally 1, Electric Circuits and Their Parts
Experimenting 4, Fermentation

A collection of objectives from the *Observing* exercises comprise the definition of the process of *Observing* for the *Observing Hierarchy,* a sequential arrangement. It is a hierarchy in the sense that the sequence has been determined by dependencies among the *Observing* objectives with a top level, bottom level, and intermediate levels.

The most complex performances named by objectives in the *Observing* exercises are at the top of the hierarchy. Those performances or behaviors on which the ability to perform the most complex behaviors depends are below them in the hierarchy and are joined to them by black lines. In turn, each subordinate behavior has connections leading down to other subordinate behaviors on which the higher behavior depends. This procedure of identifying dependencies is continued until the least complex *Observing* behaviors are reached. These behaviors comprise the bottom level of the hierarchy.

A hierarchy has been developed in this manner for each of the thirteen processes of science developed in *Science—A Process Approach.* These hierarchies are the skeleton of the program and constitute the rationale for the order of the exercises. Thus, the hierarchies orient you to the purposes of the program or any portion of it. You may examine the progression of the objectives displayed in the hierarchies and derive from them a view of where teaching starts and where it is expected to go. In addition, they show the interrelationships between any one exercise and others which precede or follow it, including those primarily devoted to other processes.

To aid you in maintaining this viewpoint toward the progressive development of processes, there is included in each exercise in the AAAS-Xerox editions a section called *Sequence* which shows the preceding steps relevant to the exercise and subsequent steps in the behavioral hierarchy. This section is simply a small portion of an entire hierarchy, providing you with a specific view of what has gone before and what is coming next. The interpretation of such diagrams is expected to be: (1) these are prerequisites for the present exercise; (2) these are the most important elements of what the child is expected to learn in this exercise; and (3) this is what the exercise will prepare him to undertake in later learning.

The hierarchies for the eight basic processes and the five integrated processes define these processes in *Science—A Process Approach.* They are descriptions of sequences of cumulative learning. The hierarchies are in no sense absolute in their classification or totally inclusive in their scope. Nevertheless, they give a description of the capabilities that are developed in the program.

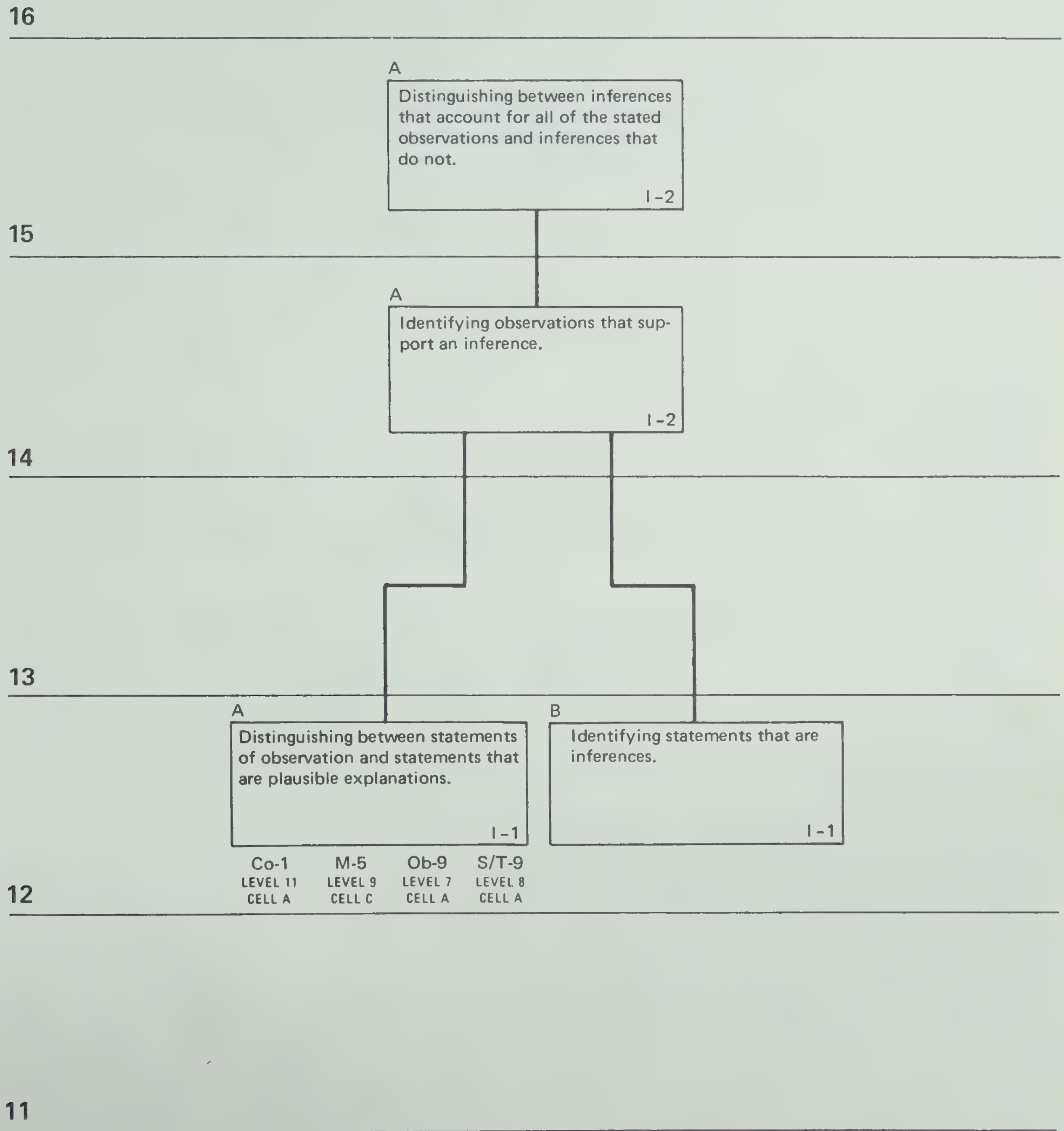

16
A
Distinguishing between inferences that account for all of the stated observations and inferences that do not.
I-2
15
A
Identifying observations that support an inference.
I-2
14
13
A
Distinguishing between statements of observation and statements that are plausible explanations.
I-1
B
Identifying statements that are inferences.
I-1
Co-1 LEVEL 11 CELL A
M-5 LEVEL 9 CELL C
Ob-9 LEVEL 7 CELL A
S/T-9 LEVEL 8 CELL A
12
11

FIGURE 2

Examine, for example, the Part C portion of the *Inferring* hierarchy, shown in Figure 2. The process of *Inferring* is introduced in Part C in the exercises *Inferring 1* and *Inferring 2.* At the lowest level (Level 12), there are two skills or behaviors, and they are objectives of *Inferring 1.* Two other behaviors or skills from *Inferring 2* appear above these two, one at Level 14 and one at Level 15. All four cells are connected by black lines to show dependencies. The most complex *Inferring* skill in Part C is the one at Level 15: *Distinguishing between inferences that account for all of the stated observations and inferences that do not.* Acquiring this skill requires the ability specified in the box at Level 14. This skill, *Identifying observations that support an inference* is also taught in *Inferring 2.* In turn, this skill depends on the two skills at Level 12 which are taught in *Inferring 1.*

In developing the program, the sequence of the skills was hypothesized. As the experiment grew, the basic process hierarchies were tested with large numbers of children. The integrated process hierarchies have not yet been tested to the same degree.

The thirteen separate process hierarchies are not independent of one another. Typically, activities designed to develop capabilities in one process contribute to the child's capability in other processes. Skills in *Observing* contribute to a child's skill in *Classifying, Measuring,* and *Communicating*. Put another way, developing a skill in one process may be dependent on the prior acquisition of skills in other processes. The hierarchy is marked to show these interdependencies. Referring again to Figure 2, you will see four triangles below Cell A of *Inferring 1.* These triangles identify exercises in other processes on which acquisition of the skill represented in Cell A of *Inferring 1* depends. The exercises are *Communicating 1, Measuring 5, Observing 9,* and *Using Space/Time Relationships 9.*

The complete hierarchies for the eight basic processes are presented on the *Basic Process Hierarchy Chart,* while the five integrated processes are shown on the *Integrated Process Hierarchy Chart.* The levels of the two *Charts* overlap a little as some of the advanced skills in the basic processes are interwoven with the elementary skills of the integrated processes. For the exercises, the overlap occurs in Part E. The integrated process skills, of course, are dependent on the basic process skills.

An explanation of the hierarchies is given in the *Description of the Program* booklet which introduces each Part of *Science—A Process Approach.* Further instructions about the hierarchies may be found in the *Guide for Inservice Instruction* and the *Response Sheets.*

The hierarchies serve a number of purposes in the conduct of the educational program embodied in *Science—A Process Approach.* First, because they are sequential arrangements of the exercise objectives, they provide you with an overview of the entire program, the program for your class, the abilities your children should have acquired before they came to your class, and the abilities they will acquire in subsequent years. The *Sequence* section of each exercise gives you that kind of information for each exercise, and the *Sequence* is part of a hierarchy.

Second, you can use the behavioral hierarchies as guides to the assessment of pupil achievement and program evaluation. The competency measures, as mentioned earlier, are performance tests designed to determine whether or not the child has achieved the objectives of each exercise. The tests, however, are also designed to be consistent with the process hierarchies, so that in each case what is being measured is a new achievement and not something that has already been achieved as a result of some earlier exercise.

Finally, the hierarchies also guide the development of measures of achievement which are terminal to the program insofar as they help to define what the totality of knowledge may be for children who have participated in the program for a period of years.

Thus, through the devices of behavioral objectives, competency measures, and hierarchies, all related to the processes of science chosen for *Science—A Process Approach,* the evaluation of the program is complete and helpful to a degree not often found in elementary science curricula.

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PART 2: THE BASIC PROCESSES

OBSERVING

OBJECTIVES

After you have studied this exercise you should be able to

1. *IDENTIFY* and *NAME* properties of an object or situation by using at least four of your senses.
2. *CONSTRUCT* statements of observations in quantitative terms.
3. *CONSTRUCT* statements of observations that describe observable changes in properties of an object.
4. *DISTINGUISH* between observations and inferences.

RATIONALE

Using the five senses to obtain information about objects and events is an essential part of science. Casual observations spark almost every inquiry we make about our environment, and organized observations form the base from which every step in a structured investigation proceeds. *Observing* is the most basic process of science.

In the first four Parts of the program, there are eighteen *Observing* exercises. Some are concerned with observing such qualities of objects as color, shape, texture, and size. There are exercises on sound, odor, and taste, and one exercise calls for the use of all five of the senses. Other *Observing* exercises have such diverse science content as weather, magnets, magnetic poles, falling objects, mold gardens, growth of seeds, and animal motion.

Careful observation is essential for any scientific investigation, whether by a kindergarten child or a research scientist. Observations lead to the construction of inferences or hypotheses that can be tested by further observations. So, observing provides both a basis for new inferences and hypotheses

and a tool for testing existing inferences and hypotheses. Throughout *Science—A Process Approach,* from the basic *Observing* exercises in Part A to the *Experimenting* exercises in Part G, the child's ability to make careful observations will be a determining factor in his success in the program.

The activities suggested on the following pages are designed to provide you with some guidelines for, and practice in, making accurate and detailed observations. Working carefully through them will help you to develop the skills stated in the objectives for this section.

VOCABULARY

quantitative observation
inference

MATERIALS

Piece of hard candy, 1
Matches
Glass of water, 1
Metric ruler, 30-centimeter
Equal-arm balance, 1
Leaves of five or more different house plants (optional)
Bar magnets, 2
Paper clips

Activity 1—Making Observations

Place these items on your work table: a piece of hard candy, a glass of water, matches, a metric ruler, an equal-arm balance, and some paper clips. Pretend that you do not know what the hard candy is. To indicate this, call it *the object.* List as many observable properties of the object as you can. Use any of the other items to help you make your observations. Be sure to make your list before reading on.

Now review your observations. Here are some questions to use as you check your list.

1. How many of your senses did you use?
2. Did you include any quantitative observations? For example, did you measure the size or weight of the object?
3. Did you list any observations that involved a change? Did you use the water or the match to change the properties of the object?
4. Did you include any inferences in your list of observations? For example, did you say that the object was candy? If you said it was candy, ask yourself if candy is a property you can actually observe with your senses. If you hadn't known that the object was hard candy, would you have known for sure that the object wasn't something else, like a herbicide, a fertilizer, or even a poison disguised to look like candy?

After thinking about these questions, add to your list of observations and delete any statements which appear to be inferences rather than observations. The following activity will provide you with some guidelines that should enable you to make more complete and accurate observations.

Activity 2—What To Look For

In preparing to report observations, consider these basic ideas:

1. Observations are made through other senses than sight alone
2. Observations should be quantitative whenever possible
3. Observations should include statements about change whenever possible
4. Observations should be distinguished from inferences

USING ALL OF YOUR SENSES

In this program, observing is defined as using several or all of the senses—sight, touch, hearing, taste, smell—to find out about an object. Observing requires that you pick up objects, feel them, shake them, press them, smell them, and do all the things which help you obtain sensory information about the object. It does not involve visual inspection alone. A word of caution, however: You may have noted that *Objective 1* for this section specifies "using at least four of your senses." It does not specify the use of five senses because the sense of taste needs to be used with care. Because some things are poisonous or harmful, you must warn your children that they should not taste unknown objects. (In the preceding *Activity,* of course, you knew what the candy was, and you probably tasted it.)

Check your list of observations to see if you used the following senses and included references to properties of the object like these:

Sight: sides are circular (or square, oval); color is red (or yellow, green)
Smell: smells fruitlike (or like peppermint)
Taste: tastes sweet (or like lemon)
Touch: feels smooth (or rough); feels hard
Hearing: makes a sharp sound when dropped on the table

Statements like these are called *qualitative observations.*

MAKING QUANTITATIVE OBSERVATIONS

Quantitative observations are observations that include a reference to some standard unit of size, weight, temperature,

and so on. The reference may be approximate, such as room temperature, or the size of a pea. Or it may refer to some standard unit of measurement, such as a temperature of 25°C, or a diameter of 7 millimeters. Quantitative observations communicate more precise information than qualitative observations. And quantitative observations that refer to standard units of measurement communicate more precise information than those that are only approximate. For example, consider these statements:

The room was large.
The room measured 9 meters by 13 meters

The second statement tells the size of the room by reference to a standard unit of measurement (the meter); it is more precise than the first statement. The first statement is open to interpretation. Does it mean that the room was as large as a warehouse? If the statement read, "The room was about the size of an apartment living room," it might communicate a better idea of the room's size (if the writer and the reader happened to share the same experience of apartment living rooms), but it would still not provide as precise information as the statement that the room measured 9 meters by 13 meters.

Suppose you had made the following observations about the piece of hard candy you have been working with:

Size: 2 centimeters long, 2 centimeters wide, 1 centimeter thick
Weight: balanced by two small paper clips
Texture: smoother than a sugar cube; not as smooth as glass
Sound: makes a sharp click when dropped on a table

The observation about the size of the object is clearly quantitative, for it refers to an accepted standard, the centimeter. The observation about the weight of the object is quantitative, too, even though it refers to a standard which is not commonly accepted. (The weight of a paper clip can easily be converted to metric units by weighing it.) The observation about texture includes comparisons and so is a quantitative statement, though not as precise as the first two. Can you add any quantitative observations to your original list of the object's observable properties?

MAKING OBSERVATIONS OF CHANGES

Observing often involves doing something to the object that will produce a change. You might, for example, place the object in water, or apply heat to it, or strike it with a heavy instrument, and then observe the changes that result. During

such procedures, it is useful to note as carefully as possible the characteristics of the situation that produced the change (for example, the temperature of the water in which the object was placed) and the duration of the changing process (for example, the length of time it took to melt the object by applying a match to it).

If you used the matches or the glass of water during your observations of the candy, you might have observed and described either of the following changes:

> When heated with a match for approximately ten seconds, the object bubbles, then turns to a heavy liquid. When allowed to cool at room temperature for approximately ten minutes, it hardens but does not return to its original shape.
>
> When placed in one cup of water at room temperature, the object gradually gets smaller, and disappears after about fifteen minutes.

Review your list of observations and try to extend it by adding observations involving change.

DISTINGUISHING BETWEEN OBSERVATIONS AND INFERENCES

While observations identify characteristics that are directly perceived through the senses, inferences involve *interpretations* of observations. For example, you may notice that the street is very wet, and tell a friend that it rained. You *observed* the water in the street, but you *inferred* that it rained. Because they are interpretations, inferences are more open to dispute than observations. It is not likely, for example, that six people who look at the street you saw would argue about the observation that it is wet. It is far more likely that they would argue about the inference that it rained, especially if one of them had happened to wash his car at that spot, and another had seen a street-washer go by, and a third had seen a fire truck hosing an oil slick off the pavement at that spot. Any of those three events—as well as rain—could account for the wetness of the street, and, if no one had seen anything but the wet street, all four inferences would be equally valid. In fact, you can probably think of several other inferences which your single observation would not rule out.

One simple way to test whether statements are observations or inferences is to ask yourself through which of the senses the property or characteristic described was perceived. Is the property in question something that you saw? Something that you smelled? Something that you tasted? Something

that you heard? Something that you felt? If your answer to each of those questions is *No,* you have probably made an inference, rather than an observation. Check your list of observations once more, and see if it included any inferences which should be deleted. For your own use in listing observations and perhaps for your pupils' use as well, you might find it helpful to develop a checklist of questions to ask. Below is a sample checklist which you might use.

1. Have you observed the object's shape and color? Is the object one in a group of objects? If so, what position does it have within the group? Have you observed any odor, taste, or sound? Remember, the lack of sound, taste, or odor is important, too. Tap, bend, and shake the object. What do you see, feel, hear? Did you lift the object to estimate its weight? Have you used all your senses?
2. Have you asked questions like, "How long is it?" Did you use terms like *bright, loud, small, tiny, big, many, tall,* and others without specifying *how* loud, small, or bright? Did you refer to specific units of measurement in describing size, shape, weight, temperature?
3. Did you manipulate the object to produce a change? Did you compare the properties of the object before, during, and after a change took place? Did you observe and record the characteristics of the situation in which the change occurred? Did you observe the rate of change in appropriate units, such as seconds, minutes, or days?
4. Are you sure that all your statements are observations, not inferences? Check yourself by asking of each statement, "Which sense did I use to obtain this information?"

Activity 3—Observing Differences Among Similar Objects

In some exercises, your pupils will need to observe an object when it is grouped with similar objects. In such cases, it will be necessary to make very precise observations about the object, so that it can be distinguished from similar objects in the group. In other words, you and your children will need to be skilled in making observations which point to those features of an object that make it unique. The following *Activity* provides you with an opportunity to test your skill in making those kinds of discriminating observations.

Obtain several kinds of plant leaves. Pick one of the leaves and make a list of observations which, in combination, will apply only to the leaf you have chosen. Your object should be to enable someone else to select the correct leaf from the

group, using only your list as a guide. In making your observations, use four senses if you can, and use taste only if you are sure that none of the leaves is poisonous.

If it is inconvenient to find leaves, you can still try this *Activity* by using Figure 1. (Ability to make observations of sketches is often just as important as ability to make observations of actual objects.) Figure 1 shows sketches of leaves of seven common types of house plants. Shading is used to indicate the relative darkness of the green of the leaves, with the heaviest shading for the darkest green and the lightest for the palest. You may assume that the leaves are drawn life-size.

Suppose you made the following list of observations about one leaf in Figure 1:

1. This leaf is neither dark green nor light green
2. It is more oblong than round
3. Its veins are distinct
4. It has a central vein that separates the leaf into two equal parts

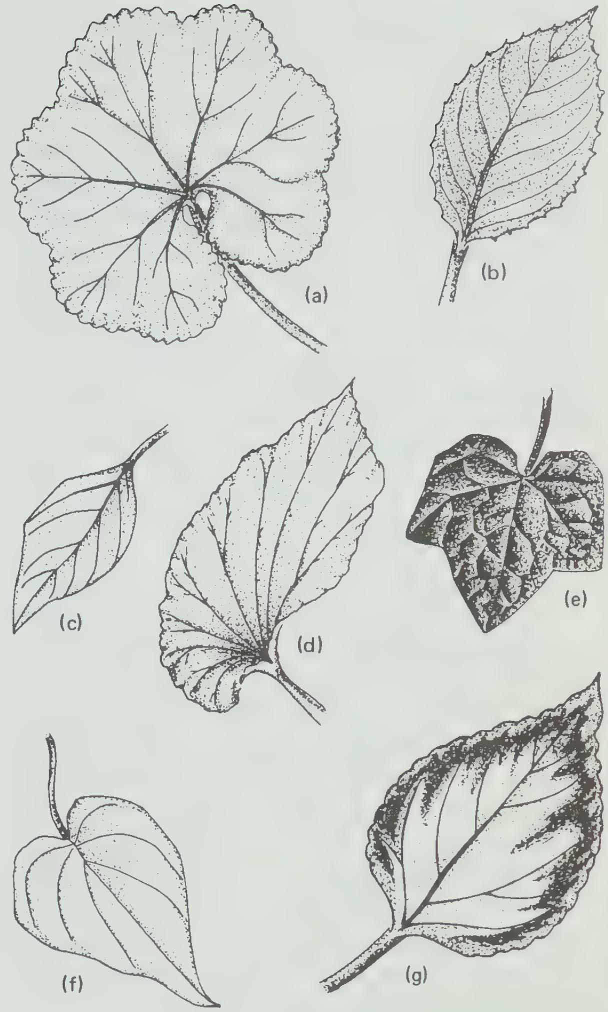
Those observations would apply to four of the seven leaves. To achieve your objective, you would have to add several more detailed observations to your list. If you are working from the sketches alone, you might give some attention to color distribution, apparent smoothness, and size. If you are working with real samples of leaves, you might consider odor and taste, as well.

Activity 4—Observing a Magnet

A bar magnet presents you with a different kind of problem in making observations. Can you tell that it is a magnet by looking at it? By tasting it? By smelling, touching, or listening to it? No, you cannot. To observe that it is a magnet, you will need to manipulate it in certain ways, not to produce a change in the object, but to produce observable effects in its relationship with other objects. To carry out the following manipulations, you will need two bar magnets and several identical iron objects, such as paper clips.

Touch one end of the magnet to a paper clip. What do you observe? Lay the magnet on the table and touch one end of the paper clip to several different places along the sides and at the ends of the magnet. What do you observe?

Place one bar magnet on the table and slide a similar magnet toward it so that the ends of the magnets are approaching each other. Slide the magnet you are holding as close as you can to the magnet on the table. Then, turn the magnet on the table around so that the opposite end is pointed toward the magnet you are holding. Again, slide the magnet in your



(a)	Geranium	(e)	Ivy
(b)	Fuchsia	(f)	Philodendron
(c)	Impatiens	(g)	Coleus
(d)	Begonia		

FIGURE 1

hand toward the magnet on the table until the ends of the two magnets are close together. What do you observe in each case?

Hold a bar magnet in a vertical position and suspend two paper clips from the lower end of the magnet. The paper clips should be side by side with their upper ends against the end of the magnet. What do you observe?

Place two bar magnets on the table with their ends together. Pull the magnets apart and place a paper clip between the ends. Slowly pull the magnets apart until the paper clip is disconnected from one of them; repeat several times. Then, reverse both magnets and make several similar observations. Does the paper clip disconnect in a random fashion from the two magnets, or does it disconnect more frequently from one magnet than from the other?

Following is a brief review of the probable results of the manipulations suggested. Check your observations to see if they correspond with the descriptions provided.

In the first series of manipulations, you probably noted that the paper clip was attracted most strongly to the center of the end of the bar. It was also attracted strongly along the sides near the ends of the magnet, but not in the middle of the bar. When one magnet is moved toward another magnet that is lying on the table, the magnet on the table starts to move toward the approaching magnet when they are about one centimeter apart. When the magnet on the table is reversed, it begins to slide away and turns sideways when its end and that of the approaching magnet are about one centimeter apart.

In the second series of manipulations, the upper ends of the paper clips hanging from the end of the magnet are separated by a millimeter or so. If the upper ends of the paper clips are pushed together and released, they immediately separate again. The lower ends of the paper clips are separated by one centimeter or more. If the lower ends are held together between the fingers and then released, they move apart again.

In the third series of manipulations, you may have observed that the paper clip disconnected from each of the magnets in a random fashion in successive trials, or you may have observed that the paper clip disconnected from one magnet every time. Since either of these observations would have been reported in terms of the number of times the paper clip disconnected from each magnet, either observation is quantitative.

What you have been doing in this *Activity* is manipulating an object (the magnet) in conjunction with other objects (the paper clips) in such a way as to produce observable events which you described and recorded.

SELF-EVALUATION

Make a list of observations of a wooden match. Use as many of your senses as you can, and include quantitative observations whenever possible. Then light the match and record your observations again. When both lists are complete, check to see that all your statements are observations, not inferences. The following questions should help you to determine how well you observed.

1. What colors did you observe before you lighted the match? What colors did you observe during and after its burning?
2. Did the match have an odor before burning? Did the odor change?
3. What were the dimensions of the match before burning? How rapidly did the length of the match change during burning?
4. What was the texture of the match? Was the burned part softer before or after burning?

USING SPACE/TIME RELATIONSHIPS

OBJECTIVES

After you have studied *Section One* you should be able to

1. *CONSTRUCT* drawings of common three-dimensional shapes.
2. *IDENTIFY, NAME,* and *DEMONSTRATE* the line of symmetry of a two-dimensional shape and the plane symmetry of a three-dimensional shape.
3. *IDENTIFY* three-dimensional objects from their projections in a shadow box.
4. *IDENTIFY* the two-dimensional shapes made when three-dimensional objects are sectioned in specified planes.

After you have studied *Section Two* you should be able to

1. *NAME* the time in minutes and seconds from a stopwatch for a variety of activities.
2. *STATE* and *APPLY THE RULE* for determining the linear speed of a point on the circumference of a revolving wheel.
3. *CONSTRUCT* vectors to represent relative motion.

RATIONALE

Essential to the study of any aspect of science is the description of physical environment. *Using Space/Time Relationships* is the process that develops skills in the description of spatial relationships and their change with time. It includes a study of shapes, symmetry, motion, and rate of change. The seventeen exercises in this process can be grouped into four general categories: Shapes, Time, Direction and Spatial Arrangement, and Motion and Speed.

At whatever point you enter the presentation of this process, you will need to be conversant with simple two- and three-dimensional shapes, with shadows of three-dimensional objects, with the notion of symmetry, and with cross-sections or cuts through objects. Finally, you will also need to be able to draw three-dimensional objects realistically.

If, in turn, third-grade children can "construct pictures of a cube, a rectangular prism, a pyramid, and a cylinder, first showing all edges and then showing only the edges that are visible," which is one objective of *Two-Dimensional Representations of Spatial Figures, Exercise s,* Part D, they will be able to do what many college students cannot now do. They will reinforce the skill, and their awareness of shapes in the immediate environment, in several exercises in *Communicating* as well as in general school experiences (as in art work, for example). But this skill is only one of those necessary for competence in *Using Space/Time Relationships.*

The concepts of direction and location in space relate to three-dimensional representation. The addition of what is sometimes called the fourth dimension, time, leads to the more sophisticated aspects of space/time relationships—namely, changes in position and the *rate* of change of position (speed), which may then be coupled with the *direction* of change to give *velocity,* both linear and angular. Aside from introducing the simple notions of location and movement and the techniques of time-keeping in terms of measuring time intervals, the more complicated aspects of *Using Space/Time Relationships* are reserved for Parts D and E of *Science—A Process Approach.* And again, the skills developed are reinforced in the *Communicating* sequence.

For this discussion of the process, you will find activities relating to *Shape* in *Section One* and activities relating to *Motion and Speed* in *Section Two.*

MATERIALS

For Section One

Paper shapes including a circle, a square, a rectangle, a triangle, and an ellipse, 1 set
Scissors, 1 pair
Stiff cardboard to make cutouts of the five shapes
Ball of string, 1
Modeling clay, gum rubber eraser, or a block of styrofoam, 1
Orange, 1

For Section Two

Stopwatch, 1
Ball, 1
Jar or can lids of different sizes, 4
Ball of string, 1
Meterstick and/or metric ruler
Protractor, 1

SECTION ONE – SHAPE

Activity 1 – The Symmetry of Shapes

Consider the set of five paper shapes: a circle, a square, a rectangle, an ellipse, and an equilateral triangle. Demonstrate to yourself, by folding each of them in turn, that each of these shapes is symmetrical about a line; that is, it can be folded along the line so that the halves match exactly.

Which shape has two lines or *axes* of symmetry? Question 1

Which has three? Question 2

Which has four? Question 3

Which has more than four? (How many more?) Question 4

With scissors, cut a folded piece of paper to produce an object that has only one line or axis of symmetry. The term *bilateral symmetry* is sometimes reserved for such a figure even though any object with line symmetry might properly be so labeled. A *three-dimensional* object which has symmetry with respect to a *plane* is also said to have bilateral symmetry.

One way to determine symmetry with respect to a plane is to try to decide whether the object could be cut into two parts so that the two parts would match (be mirror images of each other). That is, if you cut the object in two and placed one half on a mirror, would the object plus its image in the mirror look like the original object? (See Figure 1.)

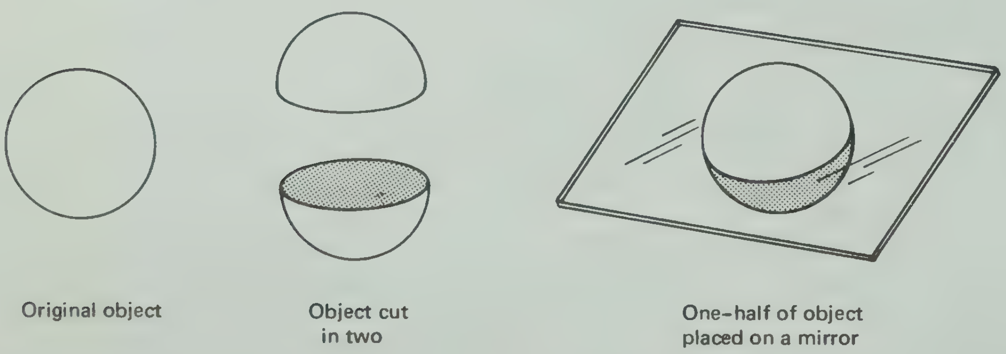


FIGURE 1

Some objects, like an orange or a cube made out of modeling clay, can actually be cut into two equal parts, but there are many other objects that you could not or would not want to cut. The bilateral symmetry of a plant or animal is an approximation, and you would not want to cut either in order to demonstrate its symmetry. Nevertheless, symmetry is a useful property to identify in describing plants and animals.

Which of the following three-dimensional objects have symmetry with respect to a plane?

Question 5

1. A church bell
2. A brick
3. An apple
4. A coffee cup
5. An automobile
6. A banana
7. Your school building

In *Science—A Process Approach,* children are asked to identify symmetry with respect to a line for two-dimensional objects and symmetry with respect to a plane for three-dimensional objects. There are, of course, other types of symmetry, and you should avoid saying an object is non-symmetrical when it does not have symmetry with respect to a line or plane. (Comments on Questions 1–5 are at the end of this *Section.*)

Activity 2 — The Relationship of Two-Dimensional Shapes to Common Three-Dimensional Shapes

In Part A, children begin to learn about the relationship between two- and three-dimensional shapes. They realize that various two-dimensional shapes are components of three-dimensional shapes. *Activities 2* and *3* consider the following relationships of shapes.

1. Some two-dimensional shapes can be drawn on or appear as the edges of some three-dimensional shapes. For example, the edges on one face of a cube form a square; a circle can be drawn on a cylinder
2. Some three-dimensional shapes are generated by rotating a two-dimensional shape
3. Shadows of three-dimensional shapes are two-dimensional shapes
4. Plane sections or cuts of three-dimensional shapes can be described as two-dimensional shapes.

The first two relationships are discussed in this *Activity.* The last two are discussed in *Activity 3.*

EDGES

On the following chart, five two-dimensional shapes are shown as headings for five columns. After each three-dimensional shape listed, check each two-dimensional shape that can be drawn around the edges of the three-dimensional shape. For example, a circle and a rectangle can be drawn around the edges of a cylinder.

Question 6

	Ellipse	Square	Circle	Rectangle	Triangle
Cone					
Cylinder					
Rectangular prism					
Sphere					
Square pyramid					

Check your answers with those at the end of this *Section.*

GENERATION BY ROTATION

Some three-dimensional shapes can be generated by rotating a two-dimensional shape. In class, you may demonstrate one or two rotational relationships and then ask children to demonstrate others. This subject is covered in *Shapes and Their Components, Exercise o,* Part A.

On stiff cardboard, draw the outlines of the five paper shapes you used in *Activity 1.* Cut these figures out. Although the pieces are actually three-dimensional (they *do* have some thickness), the cardboard is thin enough so that you can ignore the thickness and consider only the two-dimensional surface of each shape.

Make two small holes close together at opposite sides of the circle and tie a length of string about 50 centimeters long through each pair of holes. In a similar fashion, tie strings through holes at opposite corners of the square; through holes at one corner of the triangle and at the center of the side opposite the corner; through holes at the centers of two opposite edges of the rectangle; and through the opposite and more sharply curved ends of the ellipse. (See Figure 2.)

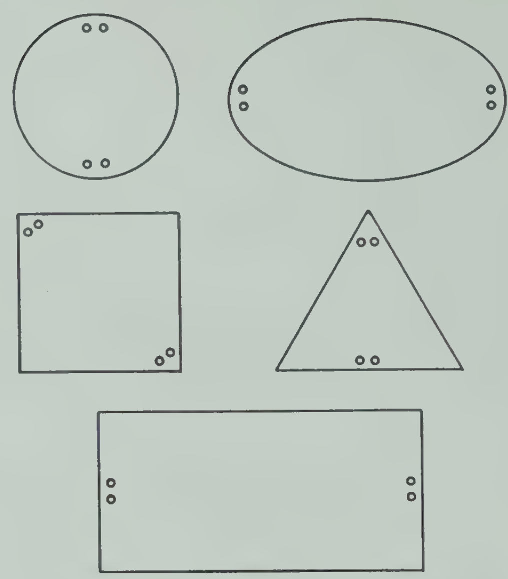


FIGURE 2

Holding the ends of both strings in one hand, wind up each shape with the other hand; then take the end of one of the strings in each hand and gently pull them in opposite directions. (See Figure 3.) Consider carefully the three-dimensional figure generated by the rotating shape as it unwinds. Do this with all five shapes and then answer the following questions. If you are not sure about any answer, wind up the shape a second time and observe it again. If you are uncertain about the correct name for the three-dimensional shape, write a description of the shape in your own words.

FIGURE 3

Question 7

What three-dimensional shape is generated when each of

the following two-dimensional shapes is rotated around a line of symmetry?

1. Circle
2. Triangle
3. Rectangle
4. Ellipse
5. Square

When you have completed your answers, check them with those at the end of this *Section.*

Activity 3 – Shadows and Sections

Children are fascinated when they realize they can identify three-dimensional shapes from the projections of their two-dimensional shadows. A shadow box is used in the exercise, *Shadows, Exercise q,* Part B. It consists of an arrangement of two screens at right angles to each other. Two light sources are placed so that one shines on each screen. When an object is placed close to the screens and illumined by the light sources, two shadows or projections of the object are visible on the screens. In diagram, the apparatus would look like Figure 4. From the rear of the shadow box, an illumined object in the box looks like Figure 5. Seen from the front, the screen might look like Figure 6. Notice that in this case, the object casting the shadows is *not* visible.

In each of the three pictures in Figure 7, a different object has been mounted in the box. The pictures are the front views of the shadow box, so that only the shadows of the objects are visible. Write the names of the three-dimensional shapes that are in the box.

If a sphere, an ellipsoid, and a square pyramid were placed in the shadow box, what shapes would their shadows have? Check your answers with those at the end of this *Section.*

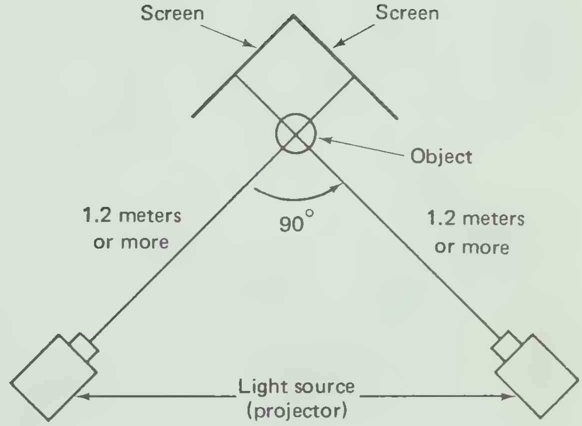


FIGURE 4

Question 8

Question 9

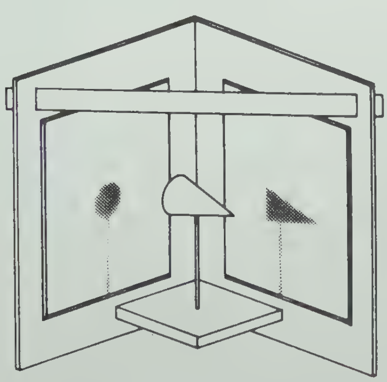


FIGURE 5

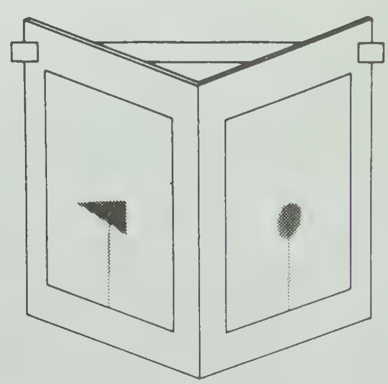


FIGURE 6

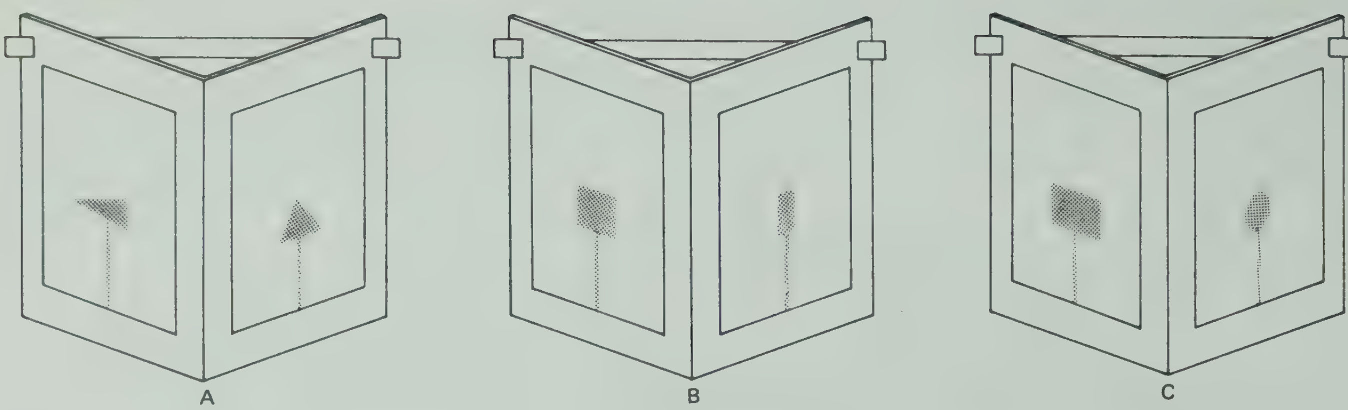


FIGURE 7

SECTIONS

In the exercise, *Inferring the Shape of Cut Things, Exercise g,* Part E, the children study another relationship between two- and three-dimensional shapes. They make slices of a cube or cylinder, for example, and observe the shape of the cut surface. When they cannot cut the three-dimensional shape, they infer the shape of the cut surface.

On the following chart, check the appropriate boxes to indicate which three-dimensional shapes could be sliced straight through at some angle to show the two-dimensional shapes. The checks are shown for a circle as an example.

Question 10

Two-dimensional / Three-dimensional	Circle	Ellipse	Square	Rectangle	Triangle
Cube					
Sphere	√				
Cylinder	√				
Ellipsoid	√				
Rectangular prism					
Triangular pyramid					
Square pyramid					
Cone	√				

Activity 4 – Drawing Three-Dimensional Shapes

Figure 8 shows six common three-dimensional shapes. In the exercise, *Two-Dimensional Representation of Spatial Figures, Exercise s,* Part D, the children learn to draw such three-dimensional shapes on a two-dimensional surface, such as a piece of paper. They view the shapes from various positions in space and learn to indicate their hidden edges.

Study the shapes in Figure 8 carefully. Jot the names of the six shapes at the top of a sheet of paper. Now, without referring to the picture, draw each one of the shapes on your sheet of paper, showing hidden edges of the figures with dotted lines. (See Figure 9 for sample sketches of a cylinder and a triangular pyramid.)

Check your sketches by referring back to the picture or by examining examples of the shapes such as balls, ice cream cones, or funnels. Practice drawing cubes, rectangular prisms, and cylinders, showing them at different orientations in space. For example, draw a square or rectangular block by sketching two identical squares or rectangles anywhere on the paper; then connect the corresponding corners with straight lines. Erasing any hidden edges will suggest the orientation of the block in space. If the two rectangles or squares differ in size, you add perspective to the figure. Erase (or dot) two edges of the smaller rectangle or square and the edge coming from the hidden corner of the smaller square or rectangle. (See Figure 10.) Constructing drawings in this way helps to associate two-dimensional figures with three-dimensional objects.

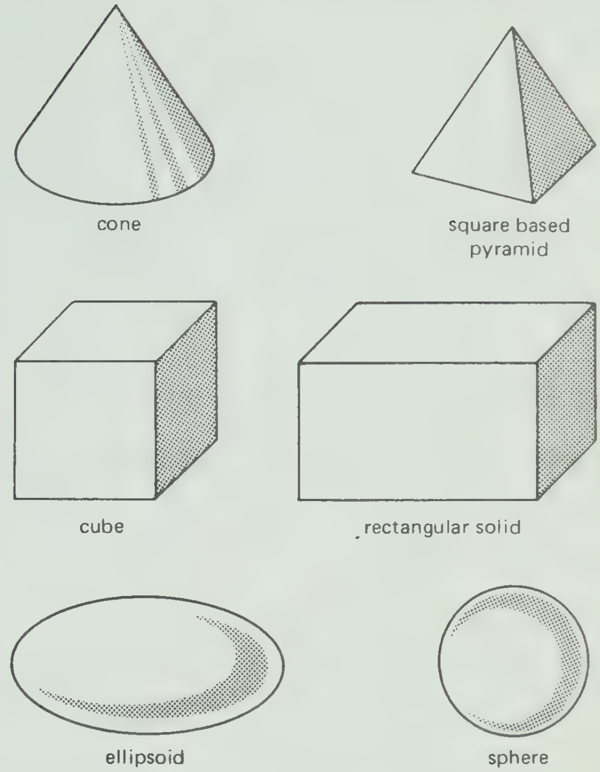


FIGURE 8

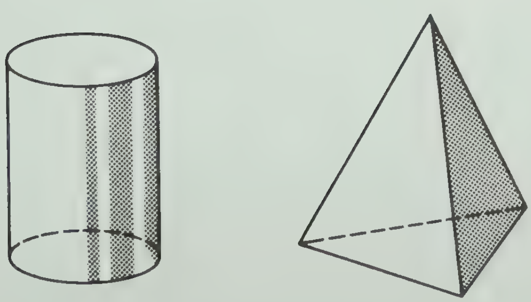


FIGURE 9

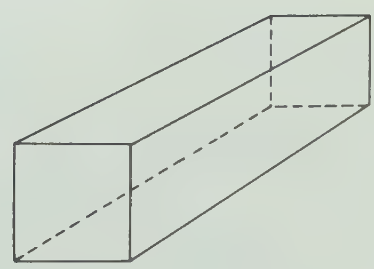


FIGURE 10

Finally, answer these questions about the shapes.

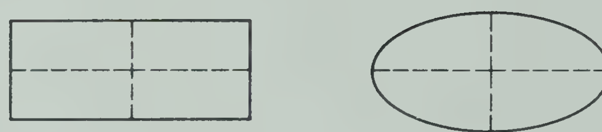
1. How many faces (flat surfaces) does a cube have? A rectangular prism? A square pyramid? Question 11
2. How many edges (junction of two faces) does a cube have? A rectangular prism? A square pyramid? Question 12
3. How many vertices (corners) does a cube have? A rectangular prism? A square pyramid? Question 13
4. On which of the six shapes shown in Figure 8 could you not draw a straight line in any direction? Question 14

Check your answers with any appropriate solid objects or with the answers at the end of this *Section.*

COMMENTS ON ACTIVITIES – SECTION ONE

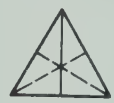
ACTIVITY 1 (QUESTION 1)

Rectangle and ellipse



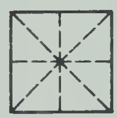
ACTIVITY 1 (QUESTION 2)

Equilateral triangle



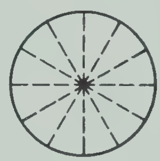
ACTIVITY 1 (QUESTION 3)

Square



ACTIVITY 1 (QUESTION 4)

Circle (An infinite number)



ACTIVITY 1 (QUESTION 5)

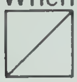
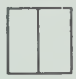
A church bell, brick, apple, and coffee cup have plane symmetry. If you consider only the outside of an automobile, then it is often symmetrical. However, if you think about the inside of a car, the halves would not match. One half would have the steering wheel while the other corresponding half would have the glove compartment, and so on.

Some bananas may not be symmetrical. Some school buildings may be symmetrical in outline as viewed from the outside. Most of them probably are not.

ACTIVITY 2 (QUESTION 6)

Cone (circle and triangle), Cylinder (circle and rectangle), Rectangular prism (rectangle, and perhaps a square), Sphere (circle), Square pyramid (square and triangle)

ACTIVITY 2 (QUESTION 7)

1. When a circle is rotated around a line of symmetry a *sphere* is generated
2. When a triangle is rotated around a line of symmetry a *cone* is generated
3. When a rectangle is rotated around a line of symmetry a *cylinder* is generated
4. When an ellipse is rotated around a line of symmetry an *ellipsoid* is generated
5. When a square is rotated around this line of symmetry a  *double cone* is produced. When it is rotated around this line of symmetry  a *cylinder* is generated

ACTIVITY 3 (QUESTION 8)

(a) Triangular pyramid, (b) Rectangular prism, (c) Cylinder

ACTIVITY 3 (QUESTION 9)

Sphere (two circles), Ellipsoid (two ellipses, or an ellipse and a circle), Square pyramid (a square and a triangle, or two triangles)

ACTIVITY 3 (QUESTION 10)

A sphere, cylinder, cone, and ellipsoid could be sliced straight through to show a *circle.*

A cylinder, cone, and an ellipsoid could be sliced straight through to show an *ellipse.*

A cube, rectangular prism, square pyramid, and cylinder with equal height and diameter could be sliced straight through to show a *square.*

A cube, rectangular prism, and cylinder could be sliced straight through to show a *rectangle.*

A cube, cone, rectangular prism, triangular pyramid, and square pyramid could be sliced straight through to show a *triangle.*

ACTIVITY 4 (QUESTION 11)

A cube and a rectangular prism have 6 faces. A square pyramid has 5 faces.

ACTIVITY 4 (QUESTION 12)

A cube and a rectangular prism have 12 edges. A square pyramid has 8 edges.

ACTIVITY 4 (QUESTION 13)

A cube and a rectangular prism have 8 vertices. A square pyramid has 5 vertices.

ACTIVITY 4 (QUESTION 14)

You could not draw a straight line in any direction on a sphere or on an ellipsoid.

SELF-EVALUATION

1. Draw a picture of a large rectangular table as seen from an angle above it. Show a cylindrical wastebasket alongside the table. Also, show several common three-dimensional shapes on top of the table.
2. Separate this set of shapes into two groups: symmetrical and nonsymmetrical with respect to a plane.

Cube	Sphere
Rectangular prism	Ellipsoid
Square pyramid	Cylinder
Triangular pyramid	Cone

3. Identify the shapes in Figure 11 that are symmetrical with respect to a line.
4. Demonstrate the symmetry of a two- and three-dimensional figure.
5. Match the name of a three-dimensional shape with a diagram of that shape; identify its pair of two-dimensional shadows; identify a section of the three-dimensional shape. (See Figure 12.)

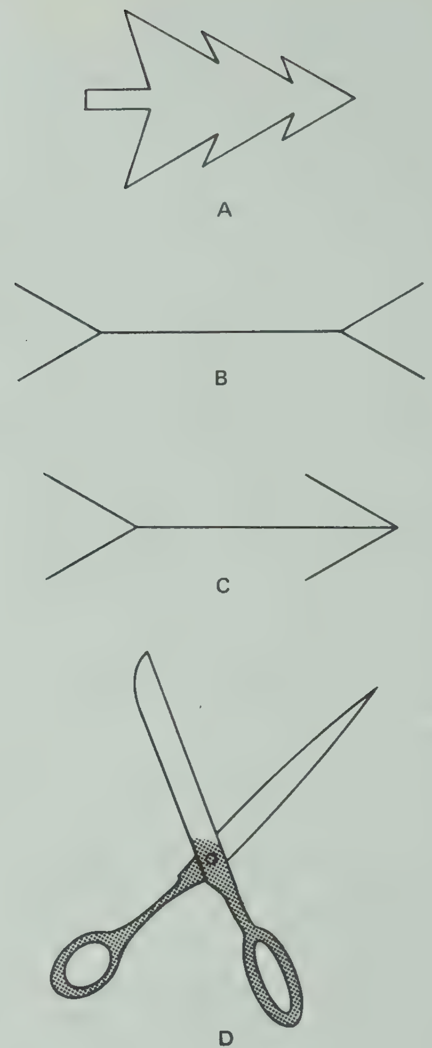


FIGURE 11

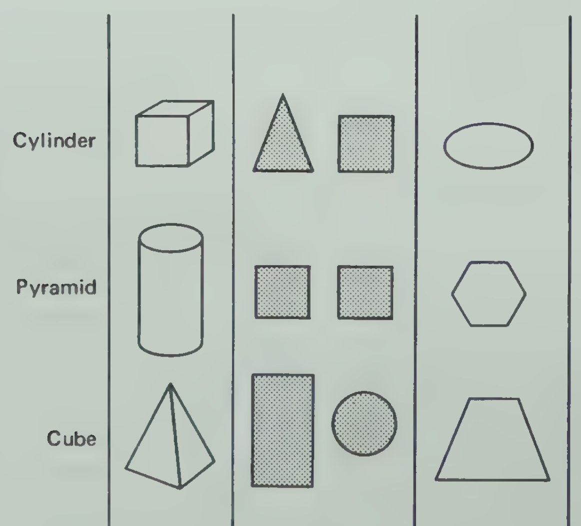


FIGURE 12

COMMENTS ON SELF-EVALUATION—SECTION ONE

1. How realistic do they look?
2. All the shapes should be classified as symmetrical with respect to a plane.
3. The symmetrical shapes are *A*, *B*, and *C*.
4. You're on your own!
5. See Figure 13.

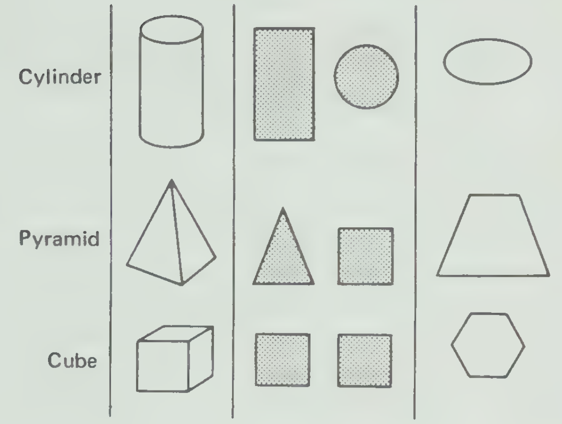


FIGURE 13

SECTION TWO—MOTION AND SPEED

Activity 1—Using a Stopwatch

Examine your stopwatch carefully. There are several different kinds. One variety is operated by pushing the winding stem. The first push starts the watch, provided it is wound up. Push the stem and verify that the second hand begins to move. Notice that the minute hand also moves and that it points to the *1* by the time sixty seconds have gone by.

Now, push the stem a second time, stopping the motion of both hands. Read the interval of time between the starting and stopping of the watch to whatever degree of accuracy you desire—perhaps 1 minute and 10 seconds, or 1 minute and 10.5 seconds. The reading can be expressed as decimal parts of a *minute* by dividing the seconds by sixty. In the case of this reading, the interval would be 1.18 minutes. Or, if you prefer, the interval can be recorded all in seconds by multiplying the number of minutes by 60 and adding the product to the number of seconds. In this instance, the reading would be 60 + 10.5 or 70.5 seconds.

Reset the stopwatch, so that both hands return to the zero position. To do this, either push the stem a third time or push the button on the side close to the stem, depending on the type of stopwatch you have.

Another variety of stopwatch operates with a sliding button on the side of the watch for starting and stopping. Whatever variety of stopwatch you are using, read carefully the manufacturer's instructions for operating and follow these precisely.

When you are familiar with starting, stopping, reading, and resetting the watch, practice timing several different events or happenings. You might try some or all of the following.

1. How long does it take you to count to 25, counting as fast as you can?
2. What is the frequency of traffic on your street? (Time the intervals between vehicles several times and take an average; or time the passage of ten vehicles and calculate the number of vehicles per minute, or per hour, on the basis of your count.)

3. Roll a ball across the floor to a wall or other obstruction. How fast can you roll it? How slowly can you roll it and still have it reach the wall?

Activity 2 — Linear Speeds of Revolving Objects

Take three or four different sized jar or can lids and measure the circumference of each one by carefully surrounding it with a length of string. Then, determine the length of the circumference in centimeters (to the nearest tenth) by holding the taut string along a meterstick. Record the circumference of each lid. Measure the diameter of each lid to the nearest tenth of a centimeter. Record these measurements in the following table.

Lid	Circumference, cm	Diameter, cm	C/D
A			
B			
C			
D			

After you have recorded the circumference and diameter of each lid, divide the circumference by the diameter and record the results in the fourth column in the table, labeled *C/D.*

If you have made your measurements carefully, pulling the string taut each time, and if you have performed the divisions correctly, you have just calculated the value of a constant known as *pi* (π). From your own demonstration you would probably accept the general statement that the ratio of the circumference of a circle to its diameter is *always* about *3.14.* This can be written as an equation, $\frac{C}{D} = 3.14$. The equation can also be written in other forms: $C = 3.14\ D$, or $C = \pi D$. An equally familiar form of the same relationship is $C = 2\pi R$ where R is the *radius* of the circle. (The radius of a circle, the distance from the center of the circle to any point on the circumference, is half of the diameter, or $D = 2R$.)

The relationship between the circumference and the diameter of a wheel has nothing to do with the *angular* speeds of rotating objects. The angular speed of any size wheel has to do with how fast it is turning. If it makes one complete revolution (through 360°) in one second, for example, then its rate is said to be 60 rpm, or sixty revolutions per minute. But, if you want to know how far such a rotating wheel will travel on a highway at that rate, then you must know the size (or diameter) of the wheel. Obviously, a small wheel will not travel as far as a large wheel at the same rate of turning. Or,

put another way, a small wheel must turn faster to cover the same distance as a larger wheel. Keep these principles in mind as you follow two sample questions and answers.

Question: A bicycle is traveling at 6 kilometers per hour (6 km/hr). How fast is that in meters per minute?

Answer: You want to convert the relationship of

$$\frac{\text{km}}{\text{hr}} \text{ to } \frac{\text{meters}}{\text{minute}}$$

1 km = 1,000 meters, 6 km = 6,000 meters

1 hr = 60 minutes

$$\frac{6 \text{ km}}{1 \text{ hr}} = \frac{6{,}000 \text{ meters}}{60 \text{ minutes}} = 100 \text{ meters per minute}$$

OR, 1 minute is $\frac{1}{60}$ of an hour; therefore,

$$\frac{1}{60} \times 6{,}000 = 100 \text{ meters per minute}$$

Question: If the front wheel of the bicycle has a diameter of 1 meter, what is the angular speed (speed of rotation) of the wheel in revolutions per minute? (The bicycle continues to travel at the rate of 6 kilometers per hour.)

Answer: The diameter of the wheel is 1 meter.

The circumference of the wheel is 3.1 meters (using $\pi = 3.1$).

Six kilometers per hour is the same as 100 meters per minute (from the previous question).

$\frac{100}{3.1}$ is the number of revolutions of the wheel per minute.

$$\frac{100}{3.1} = 30.3 \text{ rpm}$$

Answer the following questions.

A car is traveling 90 kilometers per hour.

(a) How fast is that in meters per minute? — Question 1

(b) If a front wheel has a diameter of 1 meter, what is the angular speed (speed of rotation) of the wheel in revolutions per minute?

(c) Suppose another vehicle with a wheel diameter of 0.5 meter is traveling the same distance in the same time. How many revolutions must its wheels make per minute?

Question 2

A pulley belt is moving on two wheels which are 30 centimeters and 20 centimeters in radius, respectively. A motor turns the large wheel at 60 revolutions per minute.

(a) How fast does the small wheel turn in revolutions per minute?
(b) What is the linear speed of a point on the belt in centimeters per minute?

See the end of this *Section* for comments on these questions.

Activity 3 — Representing Motion with Vectors

FIGURE 14

Suppose you are sitting in a boat sailing along at ten kilometers per hour. You are facing in the same direction as the boat is moving. Are you moving? (Yes, along with the boat.) Are you moving with respect to the boat? (No, not if you sit still.) In Figure 14 at Position 2, you and the boat have moved through the water (from Position 1), past the buoy, but you are still sitting in the same position on the rear seat in the boat. You might draw an arrow of a certain length to represent the motion and direction of you and the boat, thus: 10 km/hr → Such an arrow is called a *vector*. The length of the vector is proportional to the numerical value of the speed, and the arrow tip indicates the direction of the motion.

Now suppose that the wind is blowing in the same direction in which your boat is moving, but it is blowing at 15 kilometers per hour. A vector is constructed under the one which represents the boat's motion to represent the velocity of the wind.

Motion of the boat 10 km/hr →

Motion of the wind 15 km/hr →

The wind vector is drawn parallel to the first one, 1.5 times as long as the first one, and the tip is pointing in the same direction as the first one.

For the present, we are not concerned with *why* the boat is not moving as fast as the wind. But, if someone should ask you, you would probably say that the combined forces of the friction of the boat against the water, tide, and current create a force of 5 kilometers per hour in the direction opposite to the boat's motion, thus accounting for its slower pace. You might represent such a combined force or motion by another vector like this: ← 5 km/hr

Of course, only rarely are actual motions of objects so simple as to be acting in the same direction or in exactly the opposite direction. Motions can be in any direction and vectors representing them can be so oriented. Have you ever watched a plane flying overhead appear to be traveling like a crab—that is, headed in one direction, but obviously moving along a line at an angle to the heading because of a strong crosswind?

Vectors can be used to determine the speed and direction of motion of any moving object that is acted upon by two forces in different directions. For example, if a boat is moving east through the water with a speed of 15 kilometers per hour and a current is moving southwest at 10.5 kilometers per hour, the speed and direction of the boat *over the ground* can be determined with the diagram shown in Figure 15. *Speed* is the word to use for movement expressed in distance per unit time (*km/hr*). If direction is included, the word to use is *velocity.* Velocity is distance per unit time in a particular direction.

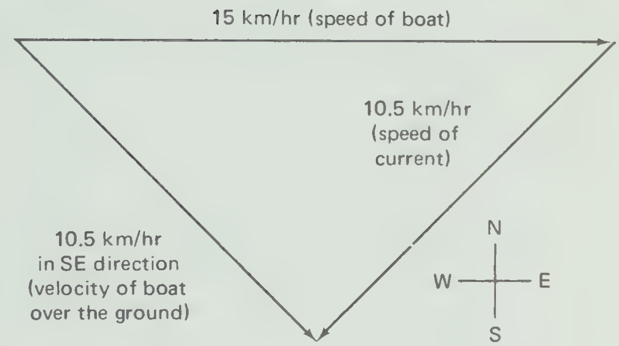


FIGURE 15

Test your ability to use these principles by completing the following tasks.

Suppose three boys, *A, B,* and *C,* are standing together. *A* faces east, *B* faces south, and *C* faces west. At a signal, each boy begins to run in the direction he faces. Each boy runs at a speed of 10 kilometers per hour. Using your metric ruler, draw a vector diagram of this situation.

Question 3

What is the speed of *A* relative to *C*?

What is the speed of *A* relative to *B*?

A plane is flying north at 800 kilometers per hour. The pilot is advised that at the altitude at which he is flying he will encounter an east wind of 400 km/hr. What is the ground velocity (speed and direction) of the plane? Construct the vector diagram and measure the velocity with respect to the ground, using a ruler and protractor.

Question 4

COMMENTS ON ACTIVITIES—SECTION TWO

ACTIVITY 2 (QUESTION 1)

a. 1,500 meters/minute. (There are 1,000 meters in a kilometer and 60 minutes in an hour:

$$\frac{\text{90 kilometers}}{\text{1 hour}} = \frac{\text{90,000 meters}}{\text{60 minutes}} = \text{1,500 meters/minute)}$$

b. 484 revolutions per minute. (If the wheel has a diameter of 1 meter, its circumference is 3.1 meters:

$$\frac{1{,}500}{3.1} = \text{484 rpm)}$$

c. 968 revolutions per minute. (If the wheel of the second car is only half the diameter of the wheel of the first car, it will have to rotate at twice the speed in order to go the same distance. Its angular speed will have to be 484 revolutions per minute multiplied by 2, or 968 rpm)

ACTIVITY 2 (QUESTION 2)

a. 90 revolutions per minute. (The angular rate of the large wheel multiplied by its radius or circumference must equal the angular rate of the small wheel multiplied by its radius or circumference, since the pulley is moving continuously at a uniform rate. This can be expressed numerically as follows:

60×30 = the angular speed of small wheel $\times$ 20, or,

$\frac{1,800}{20}$ = the angular speed of the small wheel

If you wish to calculate the circumference in each case, multiply each side by 2π or 2×3.1, but these terms cancel out in solving the equation.)

b. 11,160 centimeters/minute. (The linear speed can be calculated from the distance covered by either wheel at *its* rate:

$30 \times 2 \times 3.1 = 186.0$ centimeters = circumference of larger wheel

Multiply by 60 revolutions per minute to get linear speed in centimeters/minute.

$186.0 \times 60 = 11,160$ centimeters/minute.

Or, $20 \times 2 \times 3.1 = 124.0$ centimeters = circumference of smaller wheel

Multiply by 90 revolutions per minute to get linear speed in centimeters/minute.

$124.0 \times 90 = 11,160$ centimeters/minute)

ACTIVITY 3 (QUESTION 3)

The speed of *A* relative to *C* is 20 kilometers/hour; of *A* relative to *B*, 14 kilometers/hour. See Figure 16.

ACTIVITY 3 (QUESTION 4)

See Figure 17.

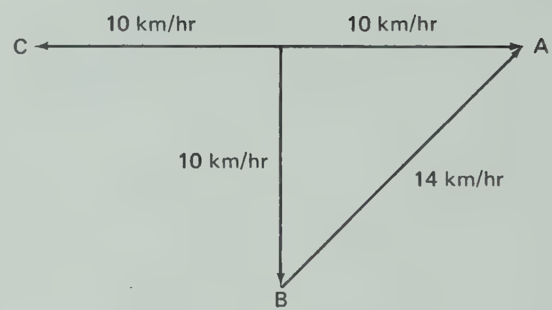
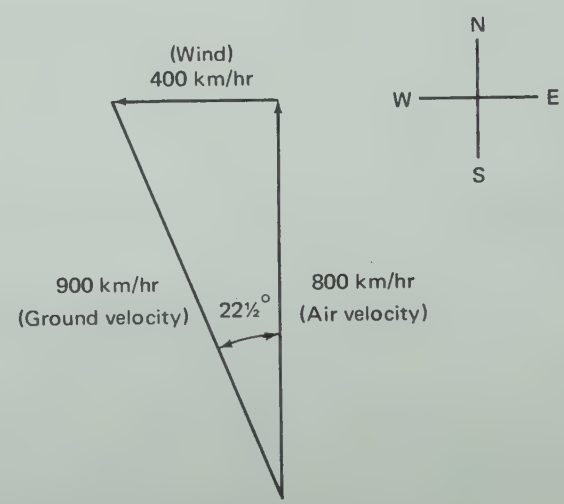


FIGURE 16



900 km/hr in NNW direction or 22½° W of N.

FIGURE 17

SELF-EVALUATION

1. What time interval is shown on each of the stopwatch faces shown in Figure 18? Express the interval in terms of the units called for.
2. A man is standing 1 meter south of the geographic north pole of the earth. Another man is standing on the geographic equator.

   a. What is the angular speed of each man?
   b. What is the linear speed of each man? (Use 12,800 kilometers as the approximate *diameter* of the earth at the equator and 3.1 as the value of π.)

3. A passenger train moves forward at 40 kilometers per hour. The passenger cars of the train form a row 1 kilometer long. A man standing on the rear platform of the last car walks through the cars toward the front of the train at the rate of 4 kilometers per hour.

   a. How fast is the man moving over the ground as he walks forward? Construct vectors to demonstrate your answer.
   b. How long does it take the man to walk the full length of the train?

(In minutes and seconds)	(In minutes, to the nearest tenth)	(In seconds, to the nearest tenth)
_____min_____sec	________min	________sec
(a)	(b)	(c)

FIGURE 18

COMMENTS ON SELF-EVALUATION

1.

   a. 10 minutes 16 seconds
   b. 4.8 minutes
   c. 673.4 seconds

2.

   a. The angular speed of each man is one revolution per day.
   b. At a distance 1 meter from the pole, 6.2 meters per day, or 0.26 meter per hour. (The curvature of the earth is negligible so close to the pole, and the radius of the circle the man will describe in space can be considered 1 meter. The circumference of such a circle is given by $2\pi R$, or *6.2 meters.*) At the equator, the linear speed is 39,680 kilometers per day, or 1,653 kilometers per hour. (The circumference of the circle described by the man in space is given by π times the diameter of the earth, or 3.1 X 12,800 kilometers or 39,680 kilometers per day.)

3.

   a. 44 kilometers/hour

      40 km/hr (Velocity of train) ⟶ 4 km/hr (Velocity of man walking through train) ⟶

      Add vectors to get velocity of man over the ground.
   b. 15 minutes (With respect to the train, the man walks 4 kilometers/hour, so it will take him one-fourth of an hour to walk one kilometer, the length of the train.)

CLASSIFYING

OBJECTIVES

After you have studied this exercise you should be able to

1. *IDENTIFY* and *NAME* observable properties of objects which could be used to classify the objects.
2. *CONSTRUCT* a one-, two-, or multi-stage classification of a set of objects and *NAME* the observable characteristics on which the classification is based.
3. *CONSTRUCT* two or more different classification schemes for the same set of objects—each scheme serving a different purpose.
4. *CONSTRUCT* an operational definition based on a classification scheme.

RATIONALE

Classifying is the process scientists use to impose order on collections of objects or events. Biologists classify organisms as plants or animals. Chemists classify certain substances as acids or bases. Physicists classify sub-atomic particles by mass, electric charge, and half-life. Astronomers classify stars by magnitude and color.

Classification schemes are used in science as well as in other areas to identify objects or events, to show similarities, differences, and interrelationships. For example, the chemist's periodic table shows families of chemical elements that have similar chemical properties even though the individual elements in each family differ in other properties such as melting and boiling points. We all classify objects and use classification schemes every day. We classify stores into categories such as groceries, drug, hardware, department, and automobile supply. Businesses of many types are grouped in the *classified* section

of the telephone book. Books in a library are classified by subject area. There are two major classification schemes used in the United States: the Library of Congress and the Dewey Decimal systems. The former system is most useful for large libraries and the latter for small libraries. This example illustrates three important principles in classifying: Classification systems are designed to be useful; classification systems are arbitrary; any group of objects or events can be classified in more than one way.

Classifying is introduced in Part A. At first children separate leaves, nuts, or shells on the basis of observable differences. Later on in *A Purpose of Classification, Classifying 2, Exercise s,* Part A, they discover that the same objects can be classified in different ways. In Parts B and C, the children observe living and nonliving things and learn to use multistage classification systems. Punch cards are used to code data in Parts D and E and the children find that they can sort the cards according to the properties they are most interested in at the time of their investigations.

To develop a classification system, you must first divide a set of objects into two or more subsets on the basis of one observable property. In this exercise, *Activity 1* discusses the properties that may be used to classify a collection of objects. You then further subdivide each subset on the basis of a second observable property, and so on, until you can identify individual objects by observing a sufficient number of properties. In *Activity 2*, you will be asked to construct a three-stage classification system. While you are deciding on the properties to use to separate the objects, you will realize that your choice depends on the purpose of your classification key. *Activity 3* is concerned with the role that purpose plays in determining the classification key you construct. In *Activity 4*, you will consider how operational definitions can be constructed from your classification keys.

The properties that are used in identifying objects can be put into an outline or a diagram which is called a *classification key.* You may have used classification keys to identify rocks and minerals, or birds, or plants. Many properties may have to be observed to identify a single object if the set of all objects is large. For example, the classification key in Gray's *Manual of Botany* lists more than twenty properties that must be observed to identify a particular species of holly.

VOCABULARY

one-stage classification
two-stage classification, and so on
properties (characteristics)
classification key
soluble
insoluble
operational definition
subsets

MATERIALS

Baking soda	White vinegar
Baking powder	Iodine solution (a few drops of tincture of iodine in water to give a clear, orange solution)
Cornstarch	Small container, 1
Powdered sugar	Graduated cylinder or measuring spoons
Powdered chalk	
Talcum powder	

Activity 1 — Properties Used to Classify a Set of Articles

Figure 1 shows a picture of a set of objects. Observe it and make a list of the observable properties (characteristics, features) of the objects.

Probably you observed that some of these objects have a curved edge or surface. A one-stage classification could be based on the presence of a curved edge or surface. (See Figure 2.) One-stage sorting of the set of shapes could also be based on number of edges or whether the object is two-dimensional or three-dimensional. What other criteria can you think of?

By sorting the objects on the basis of two criteria, a two-stage classification can be constructed. (See Figure 3.)

What characteristics might be used to add a third and a fourth stage to this classification scheme? Try it.

When you have completed your scheme, turn to *Comments on Activities* at the end of the exercise and compare your system with the one given there.

Activity 2—Constructing A Three-Stage Classification System

In this activity, you will observe some chemical and physical properties of six white powders when each is mixed with three different liquids. Collect the powders and liquids listed in the *Materials* section.

Put about one gram (one-fourth teaspoon) of one of the powders in a container (plastic pill vial, baby food jar, or small drinking glass), and add 10 milliliters (one tablespoon) or more of one of the liquids. Observe and record what happens. Then, mix each solid with each liquid and record your observations. On the basis of your observations, construct a three-stage classification system that you could use to identify each of the six solids.

Before you start, you should know the term *soluble.* Scientists say a solid is *soluble* in a liquid if it disappears (dissolves) when the mixture of solid and liquid is shaken or stirred for a few minutes.

After you have completed your observations and constructed your classification key, compare it with one possible key that is shown in the *Comments on Activities* section.

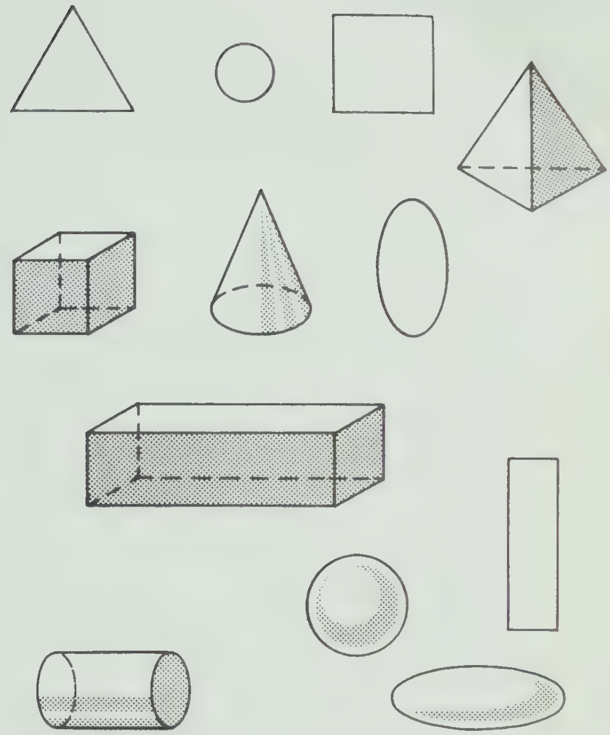


FIGURE 1

Question 1

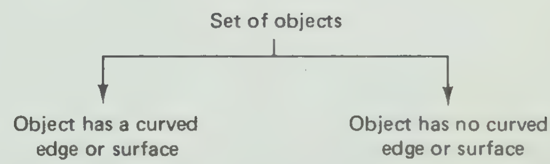


FIGURE 2

Question 2

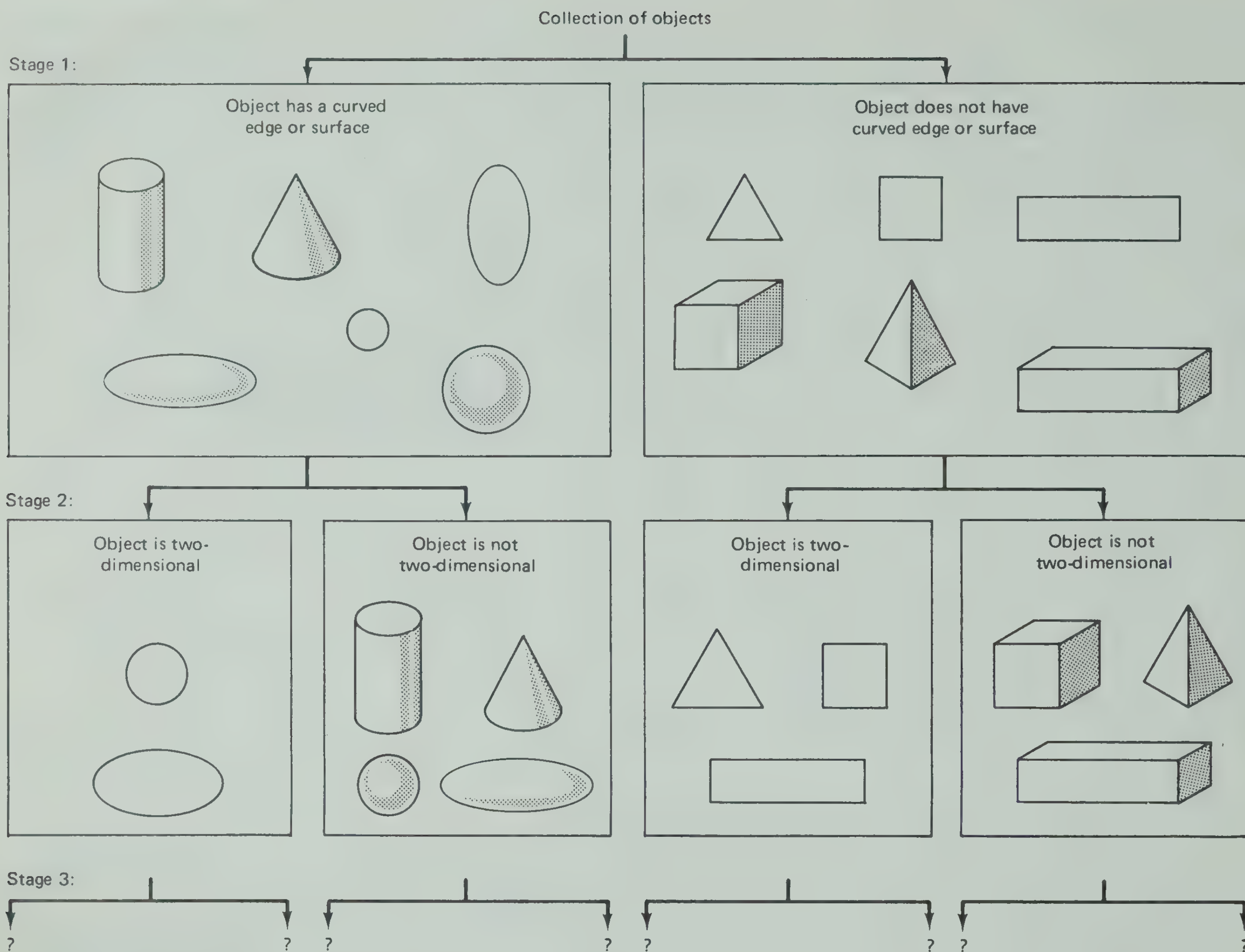


FIGURE 3

Activity 3 — Classifying for Different Purposes

Classification keys are designed to be useful. The same set of objects may be classified in different ways depending on the use that is to be made of the objects or the key. For example, suppose you want to move a box too heavy to slide, across the room. You decide that you can move it if you put some rollers under it. You have the following objects available.

1. Pieces of blackboard chalk
2. Solid steel cylinders
3. Wooden blocks
4. Broom handles
5. Cardboard mailing tubes
6. Steel ball bearings

Question 3

Design a classification key for selecting the objects you could use to move the box.

Question 4

After you have moved the box, you want to have a fire in the fireplace, but you are short of wood. Design a classification key for the same set of objects for this new purpose.

Activity 4 — Operational Definitions and Classification

The process of *Defining Operationally* is the subject of another paper in this *Commentary.* However, since defining operationally is tied closely to classifying, it will be considered briefly in this activity.

An operational definition is one that specifies what operations you perform and what you observe in order to identify an object. Consider, for example, what operations and observations would distinguish talcum powder from the other five white powders in *Activity 2.* Look at your classification key and write an operational definition for talcum powder. According to the key suggested in the *Comments on Activities,* it could be defined as follows.

> Talcum powder is a white powder that is insoluble in water, that does not foam in vinegar, and that does not turn blue-black in iodine solution.

This is an operational definition that is satisfactory for identifying which of the six white powders is talcum powder. It might not be satisfactory if the number of white powders were increased, for there are other white powders that have the three properties specified in the definition.

COMMENTS ON ACTIVITIES

ACTIVITY 1 (QUESTION 1)

For the third stage of the classification, different criteria can be used for the sets of curved objects and the sets of noncurved objects. For example, for the curved objects, you might use the system shown in Figure 4. For the noncurved objects, you might use the system shown in Figure 5.

ACTIVITY 2 (QUESTION 2)

One possible classification key for the six white solids is shown in Figure 6.

ACTIVITY 3 (QUESTION 3)

One possible classification of the objects for moving the box is shown in Figure 7.

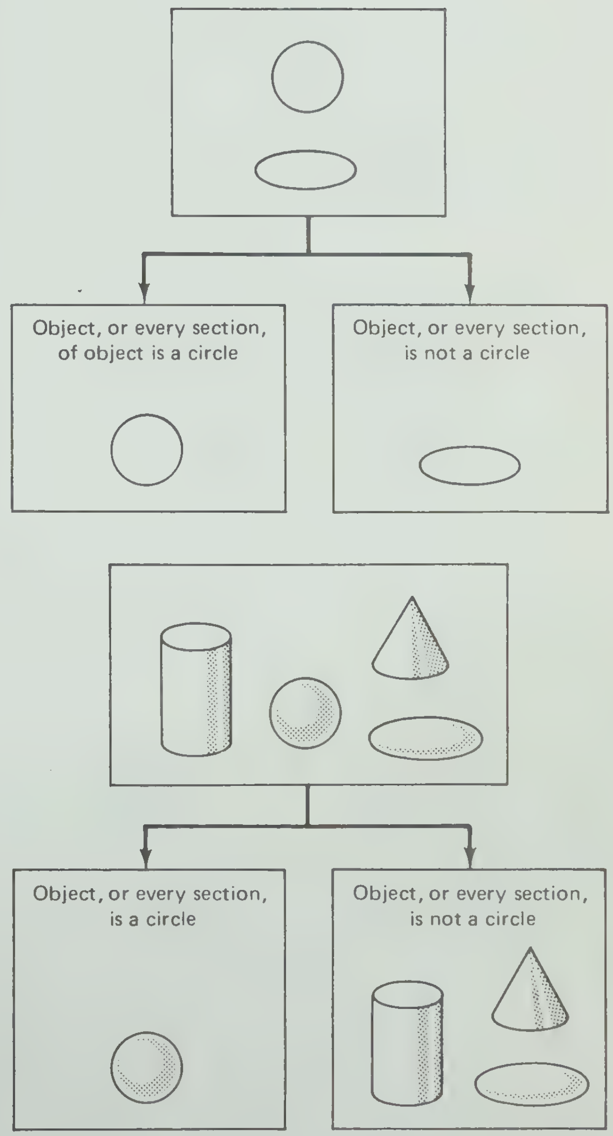


FIGURE 4

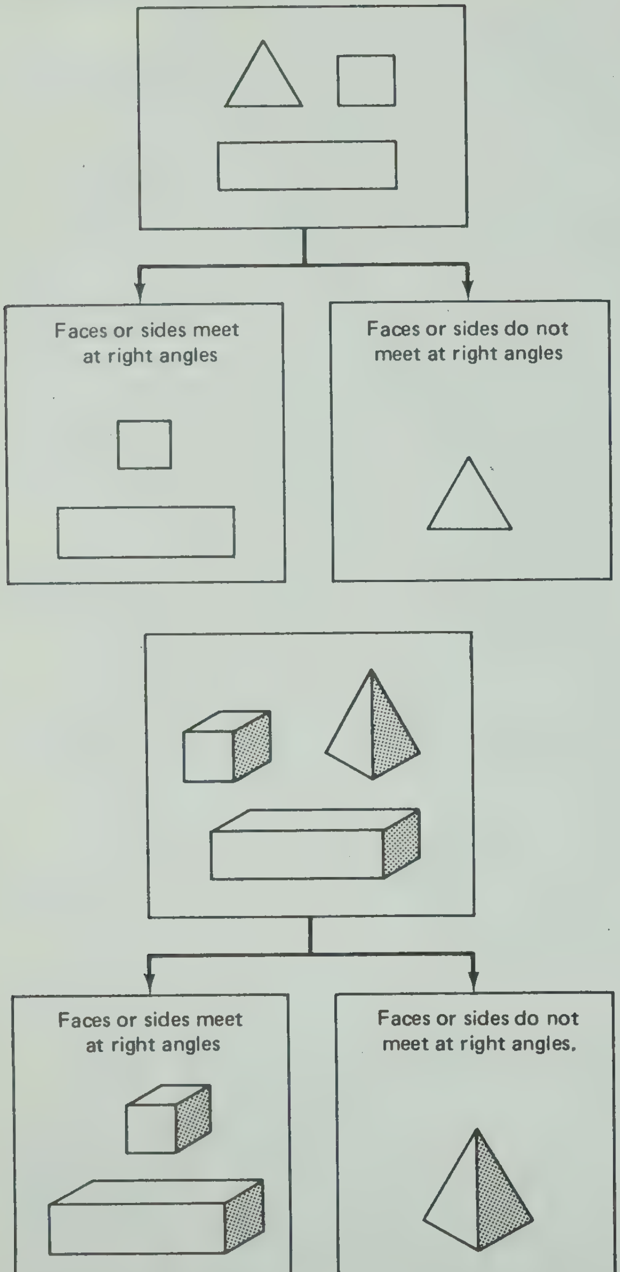


FIGURE 5

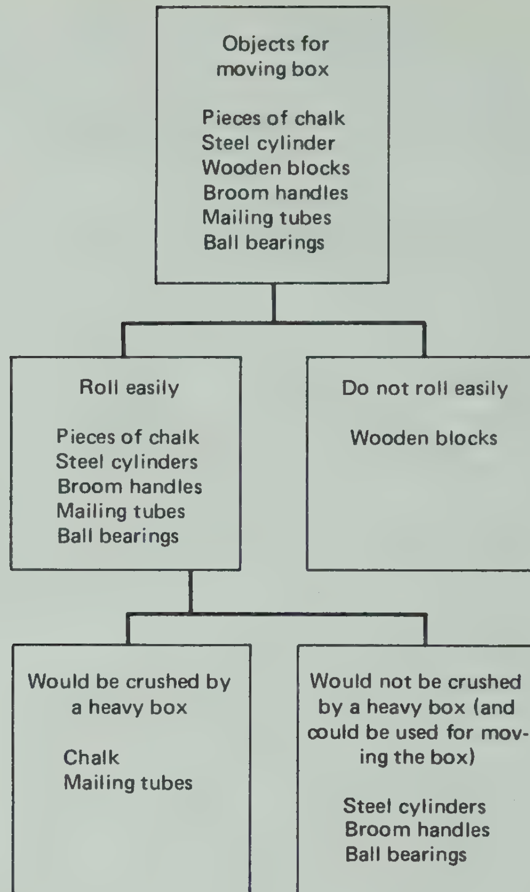


FIGURE 7

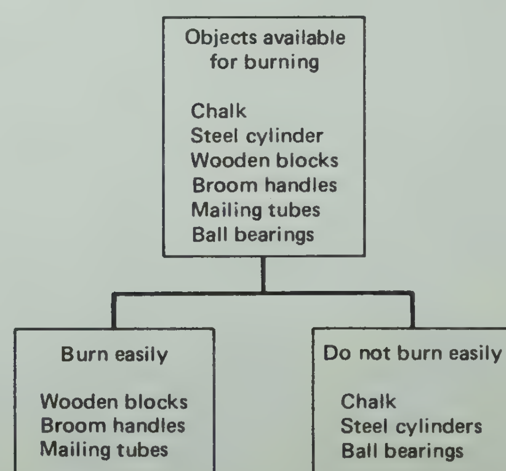


FIGURE 8

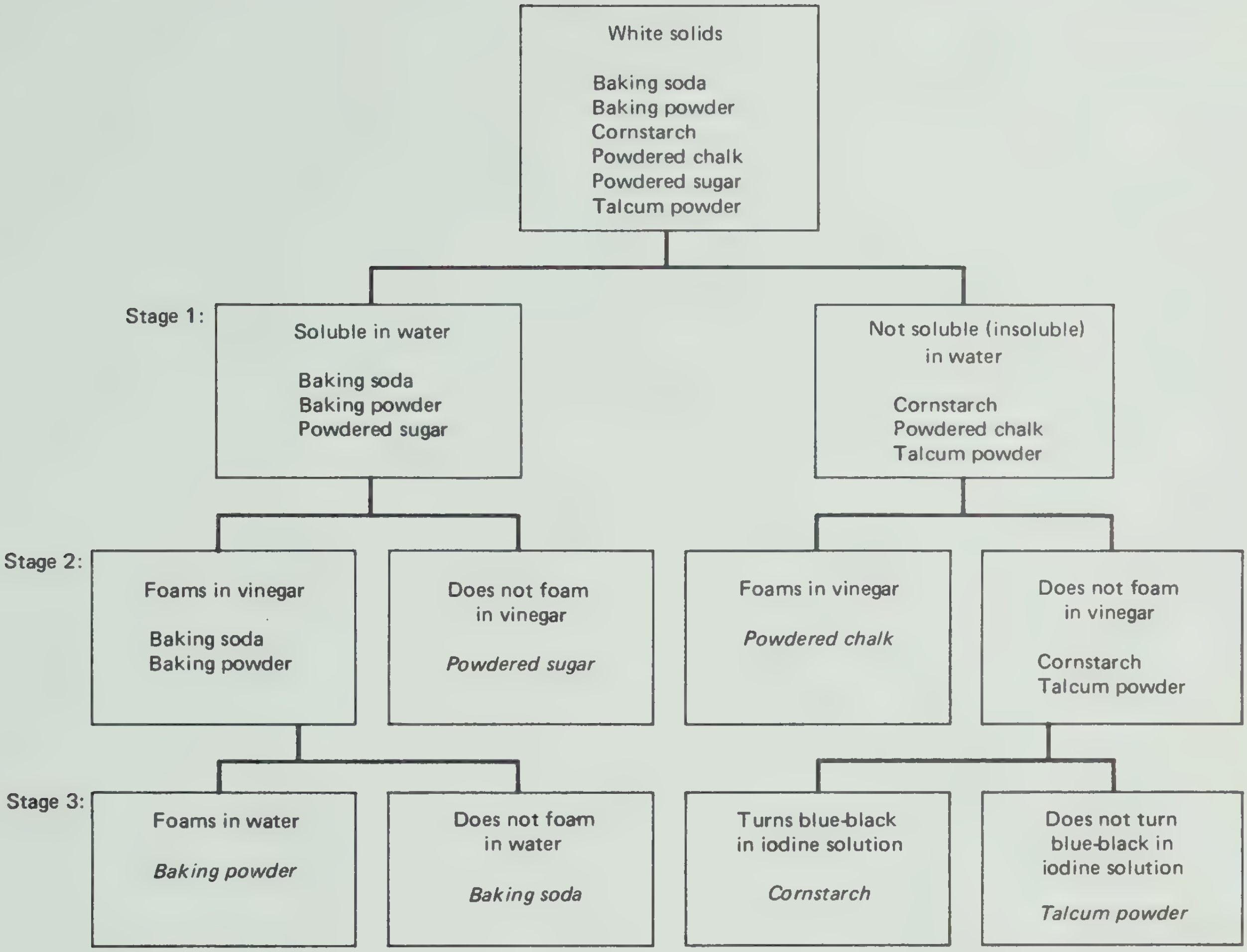

White solids
Baking soda
Baking powder
Cornstarch
Powdered chalk
Powdered sugar
Talcum powder
Stage 1:
Soluble in water
Baking soda
Baking powder
Powdered sugar
Not soluble (insoluble) in water
Cornstarch
Powdered chalk
Talcum powder
Stage 2:
Foams in vinegar
Baking soda
Baking powder
Does not foam in vinegar
Powdered sugar
Foams in vinegar
Powdered chalk
Does not foam in vinegar
Cornstarch
Talcum powder
Stage 3:
Foams in water
Baking powder
Does not foam in water
Baking soda
Turns blue-black in iodine solution
Cornstarch
Does not turn blue-black in iodine solution
Talcum powder

FIGURE 6

ACTIVITY 3 (QUESTION 4)

The second classification is a single-stage one, and of course is different from the first. (See Figure 8.)

SELF-EVALUATION

1. Given the set of pictures of leaves shown in Figure 9:
   A. Identify and name an observable property of these pictures of leaves that could be used to classify them into subsets.
   B. Construct a key for classifying the set of pictures of leaves into ten separate categories, one category for each kind of leaf. One possible classification key is shown at the end of the exercise.
2. Construct two different classification schemes for the following animals. One scheme might be based on physical characteristics and another on function.

Canary	Duck
Cat (Siamese)	Hamster
Chicken	Horse
Cow	Turkey
Dog (German Shepherd)	Pig

3. Use one of the classification keys that you constructed in Question 1 or 2 and write an operational definition of one of the objects.

COMMENTS ON SELF-EVALUATION

1. One possible key for classifying the pictures of leaves is that shown in Figure 10.
2.
   a. Classification by physical characteristics. See Figure 11.
   b. A possible classification by function is shown in Figure 12.
3. From the classification key for leaves, leaf *A* (oak) might be defined operationally as follows.

   An oak leaf is a leaf that is not divided into leaflets, that has six or more lobes, and that has depressions between the lobes that do not contact the main vein.

FIGURE 9

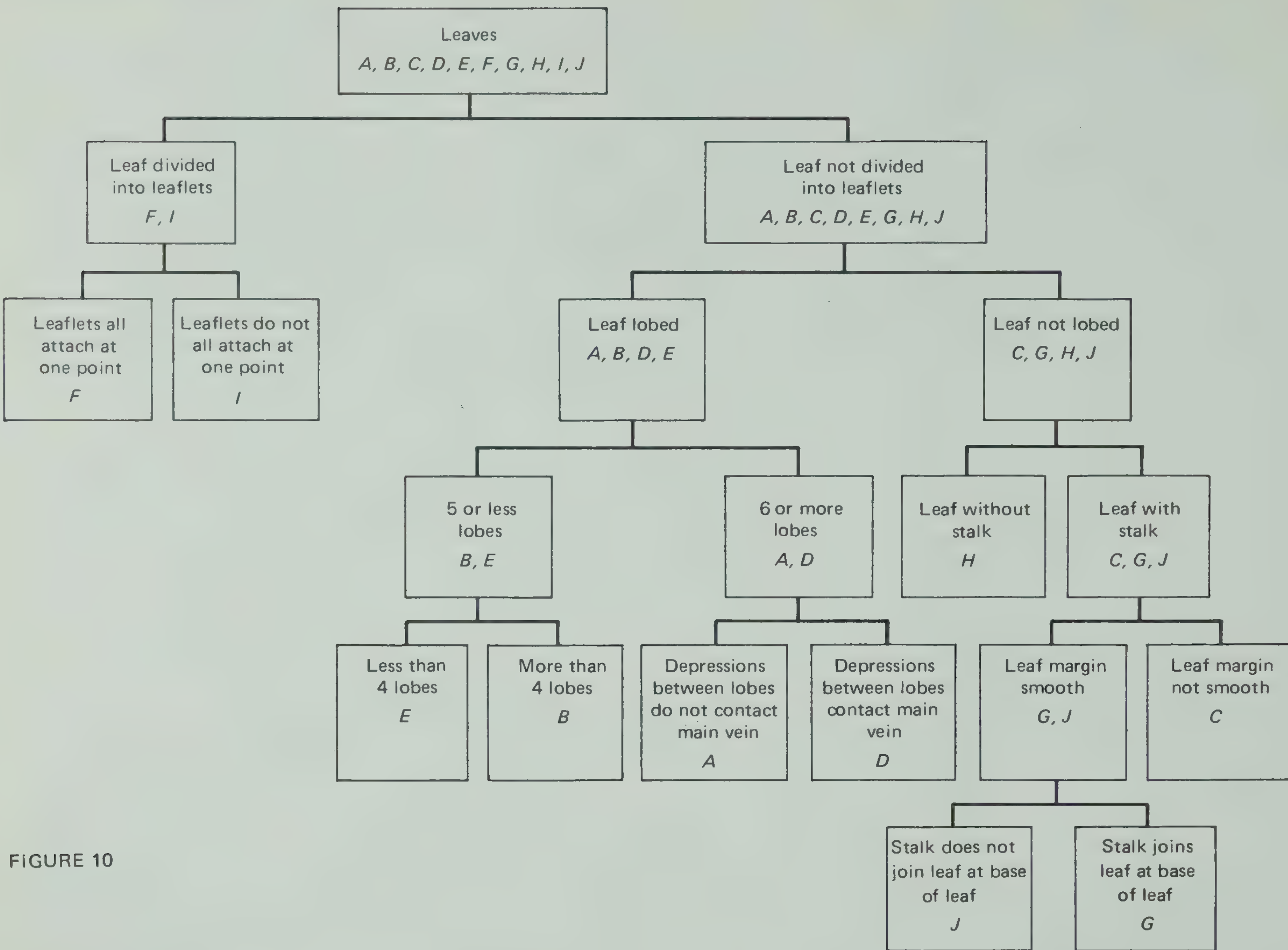

Leaves
A, B, C, D, E, F, G, H, I, J
Leaf divided into leaflets
F, I
Leaf not divided into leaflets
A, B, C, D, E, G, H, J
Leaflets all attach at one point
F
Leaflets do not all attach at one point
I
Leaf lobed
A, B, D, E
Leaf not lobed
C, G, H, J
5 or less lobes
B, E
6 or more lobes
A, D
Leaf without stalk
H
Leaf with stalk
C, G, J
Less than 4 lobes
E
More than 4 lobes
B
Depressions between lobes do not contact main vein
A
Depressions between lobes contact main vein
D
Leaf margin smooth
G, J
Leaf margin not smooth
C
Stalk does not join leaf at base of leaf
J
Stalk joins leaf at base of leaf
G

FIGURE 10

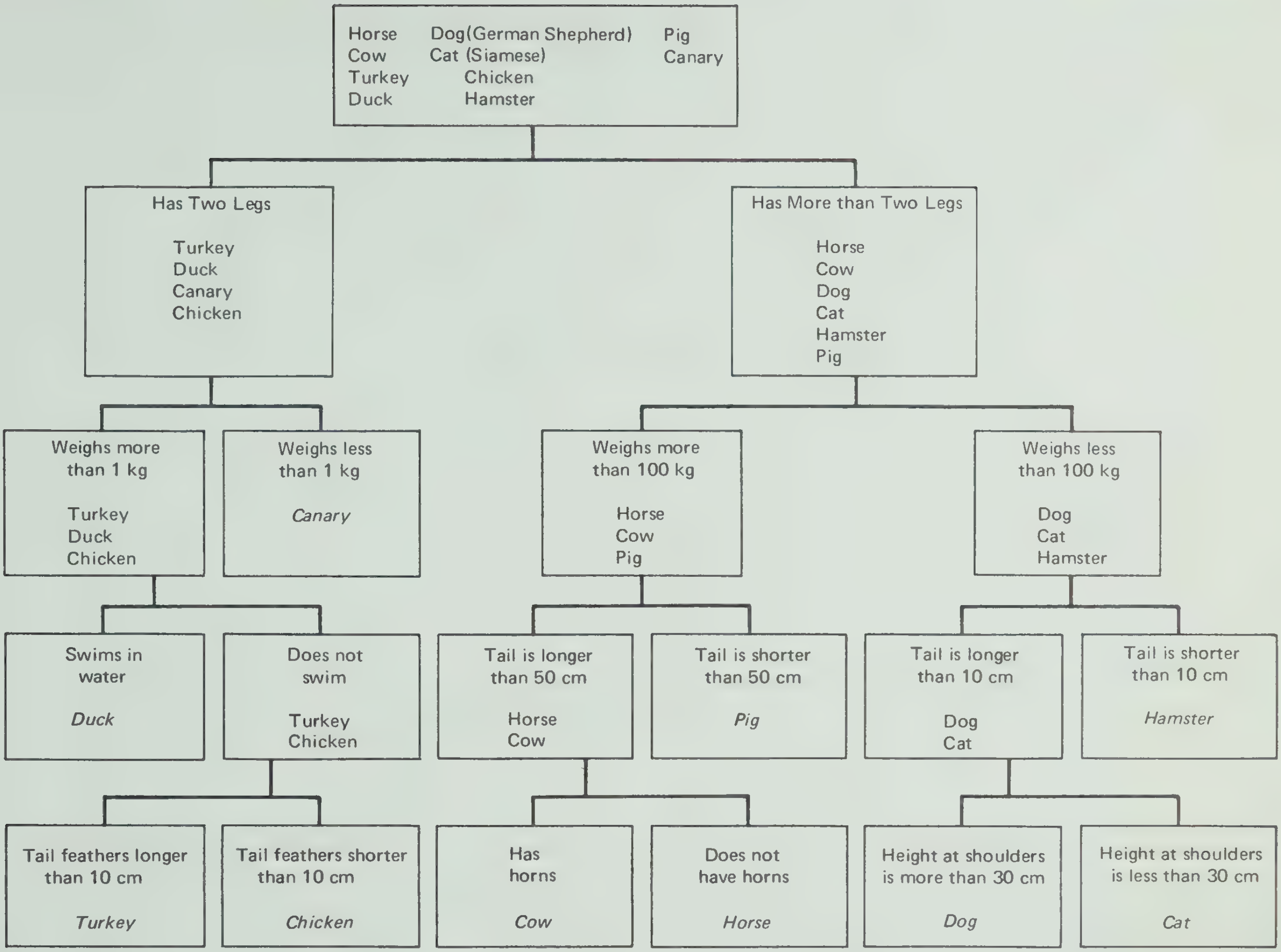

Horse Cow Turkey Duck Dog (German Shepherd) Cat (Siamese) Chicken Hamster Pig Canary
Has Two Legs
Turkey Duck Canary Chicken
Has More than Two Legs
Horse Cow Dog Cat Hamster Pig
Weighs more than 1 kg
Turkey Duck Chicken
Weighs less than 1 kg
Canary
Weighs more than 100 kg
Horse Cow Pig
Weighs less than 100 kg
Dog Cat Hamster
Swims in water
Duck
Does not swim
Turkey Chicken
Tail is longer than 50 cm
Horse Cow
Tail is shorter than 50 cm
Pig
Tail is longer than 10 cm
Dog Cat
Tail is shorter than 10 cm
Hamster
Tail feathers longer than 10 cm
Turkey
Tail feathers shorter than 10 cm
Chicken
Has horns
Cow
Does not have horns
Horse
Height at shoulders is more than 30 cm
Dog
Height at shoulders is less than 30 cm
Cat

FIGURE 11

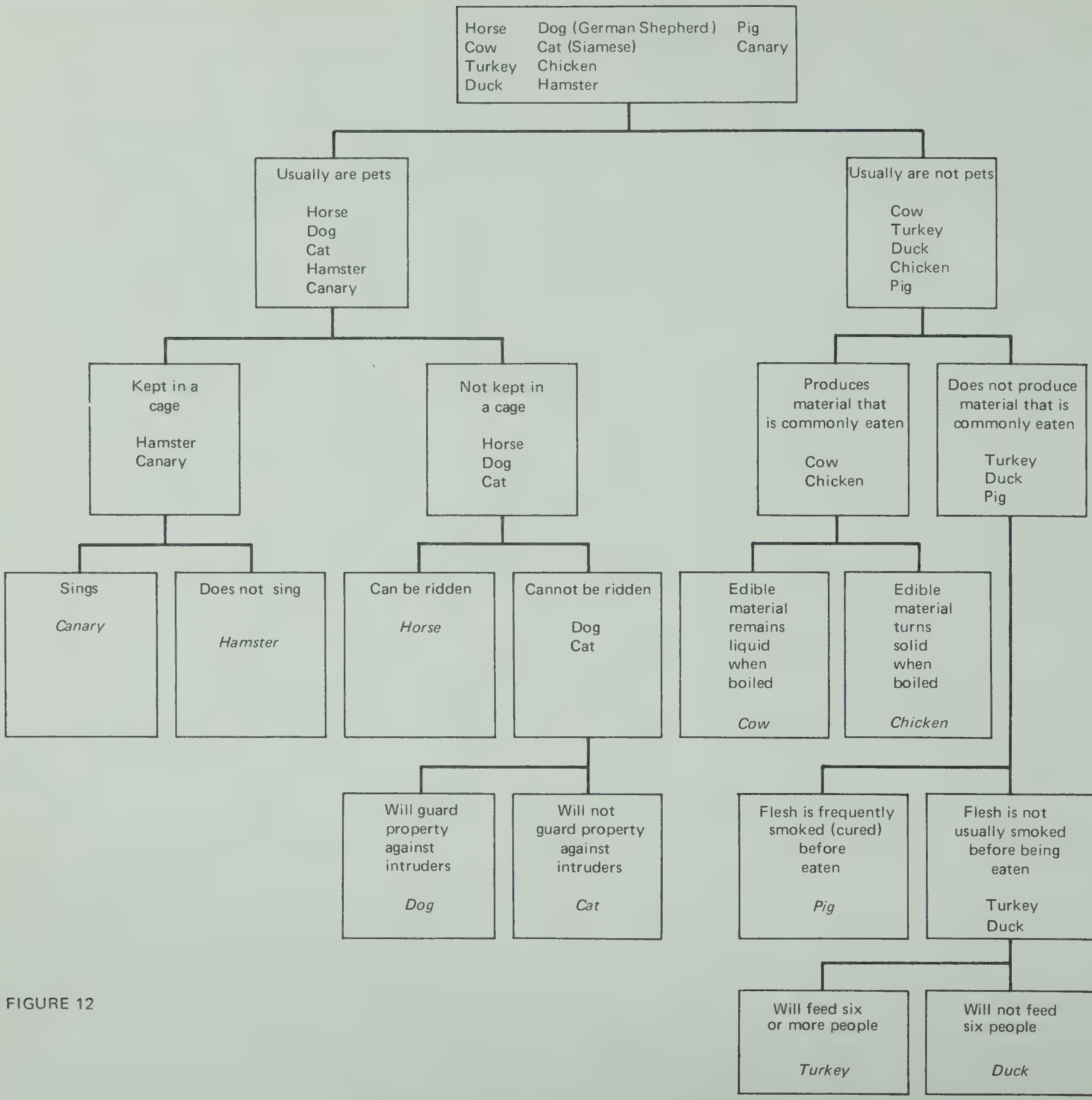

Horse
Cow
Turkey
Duck
Dog (German Shepherd)
Cat (Siamese)
Chicken
Hamster
Pig
Canary
Usually are pets
Horse
Dog
Cat
Hamster
Canary
Usually are not pets
Cow
Turkey
Duck
Chicken
Pig
Kept in a cage
Hamster
Canary
Not kept in a cage
Horse
Dog
Cat
Produces material that is commonly eaten
Cow
Chicken
Does not produce material that is commonly eaten
Turkey
Duck
Pig
Sings
Canary
Does not sing
Hamster
Can be ridden
Horse
Cannot be ridden
Dog
Cat
Edible material remains liquid when boiled
Cow
Edible material turns solid when boiled
Chicken
Will guard property against intruders
Dog
Will not guard property against intruders
Cat
Flesh is frequently smoked (cured) before eaten
Pig
Flesh is not usually smoked before being eaten
Turkey
Duck
Will feed six or more people
Turkey
Will not feed six people
Duck

FIGURE 12

USING NUMBERS

OBJECTIVES

After you have studied this exercise you should be able to

1. *NAME* points on the number line using positive and negative integers and zero, and rational numbers expressed as decimals.
2. *IDENTIFY* points on the number line given positive and negative integers, zero, and rational numbers expressed as decimals.
3. *NAME* the sum of pairs of numbers, using named points on a number line.
4. *STATE* and *APPLY RULES* for expressing the mean of a set of numbers, rates as ratios, and the decimal equivalents (or approximations) of ratios.

RATIONALE

Using Numbers is an important process of science. It differs from the other seven basic processes only because it is usually taught in an arithmetic or mathematics curriculum.

The amount of time given to the *Numbers* exercises will depend upon the mathematics program of your school. In some schools, many of these exercises can be passed over quickly when you discover, using the *Competency Measures* of the exercises, that your pupils already have achieved the objectives. In other schools, because of the quantitative nature of *Science—A Process Approach* and the nature of your arithmetic program, it will be necessary to give more time to *Numbers* exercises than that suggested by the exercises themselves.

There are two reasons to include *Numbers* exercises in the science program: first, to make pupils realize that the ability

to use numbers is a basic and fundamental process of science; second, to give the pupils an opportunity to use numbers in finding answers to scientific questions in real problem situations. In order to do the latter, *Numbers* exercises are included in appropriate places in this program to insure that the children have the number skills they need for other science activities.

In *Science—A Process Approach,* the concept of *number* is introduced in *Sets and Their Members, Using Numbers 1, Exercise f,* Part A. The concept of a set, an empty set, and equivalent sets is quite simple. Since these ideas are described clearly in *Using Numbers 1* and *2,* there is no further treatment of the subject in this *Commentary* paper. From *Using Numbers 3* on, operations with numbers are carried out using the number line, but the concept of sets is not dropped. This concept is used effectively in the *Classifying* sequence where objects are arranged in groups or sets on the basis of one or more similarities in properties. Note that this is different from the strict mathematical use of the term *set,* since the objects in a mathematical set need not have any similar properties.

This *Commentary* exercise discusses the number line, and rates and means. Most elementary school teachers have the *Numbers* competencies required to teach these topics, and you may wish to test yourself with the *Self-Evaluation* questions before studying an activity. If you have the competencies, read the activity to get the flavor of how the *Numbers* skills are introduced and used in the science program. Then, pass on to the next activity. If you do not have the competencies, study the activity carefully and try the *Self-Evaluation* again.

VOCABULARY

number line
mean

MATERIALS

Meterstick, 1
Number lines, 5

Activity 1—The Number Line

A meterstick is a good representation of part of a number line on which there are 100 equally spaced marks. If you think of the numbered edge of the meterstick as a number line and each mark as locating a point of the number line, then each of the 100 points of the meterstick number line is

associated with one of the counting numbers 1 to 100.*

If the spaces between the marks on a number line are divided into ten equal parts by other marks (or points), each of these points can be associated with a number in a similar way. For example, Figure 1 shows a part of a number line between 8 and 9. In Figure 1, points are associated with the numbers 8, 8.1, 8.2, 8.5, 8.9, and 9. What numbers are associated with the other marked points in Figure 1?

Question 1

FIGURE 1

This procedure can be carried further—indeed, as many times as you like. For example, the part of the number line between 8.4 and 8.5 can be divided into ten equal parts, and numbers associated with these new dividing points. In Figure 2, three of these points are named. What numbers should we associate with the other marked points in Figure 2?

Question 2

If ten equal spaces were marked on the segment between 8.48 and 8.49, what numbers would we assign to these points?

Question 3

In *Science—A Process Approach,* use of numbers expressed to the nearest tenth is adequate for almost all purposes, but there are a few exercises in which hundredths are used. You are urged always to write the decimal numerals from 0 to 1 as 0.1, 0.2, 0.3, and so on, except perhaps on number lines where space may limit you. This notation is then exactly like that used for numbers such as 4.9 and 17.6. Similarly, if measurements are made to the nearest tenth of a unit, it is proper to record a measurement as 6.0 when the object measured is nearer to 6 units than 6.1 units.

FIGURE 2

In Figure 1, after the points 8.1, 8.2, and so on, have been named, you should replace 8 by 8.0 and 9 by 9.0 in order to have all numbers expressed to the nearest tenth. Similarly, in Figure 2, after the points 8.41, 8.42, and so on are marked, you should replace 8.4 by 8.40 and 8.5 by 8.50.

Since the metric system of measurement is used throughout *Science—A Process Approach,* children in your classes will need to use decimal notation even before they have much skill in using common fractions. If you use the number line, you will find it quite easy to teach the needed skills in decimals and the children should find it easy to learn them. As you teach decimals, make frequent reference to the meterstick and to other types of scales in which divisions are in tenths. For example, the units on the odometer of a car are divided into tenths.

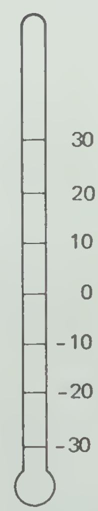


FIGURE 3

In many localities, children will be familiar with temperatures below zero. Figure 3 shows a thermometer, a representation of a vertical number line with points marked below the zero-point of the scale. Your children may have occasion to

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*In mathematics, a part of a line, as in Figures 1 and 2, is called a *line segment.* In this exercise, the shorter term, *line,* is used for convenience, and it is suggested that you use *line* in your class, unless your children are familiar with the term *line segment* from their mathematics program.

read the scale when the mercury registers below zero. How shall we name points below zero on the thermometer scale? For those points marked, the proper notation is $^{-}10$, $^{-}20$, $^{-}30$ (read as *negative ten, negative twenty,* and *negative thirty*) in that order reading down. Thus, negative numbers can be introduced using the number line.

In *Science—A Process Approach,* negative numbers are written with the raised negative symbol, as in $^{-}7$ and $^{-}28.03$. The notation is usually used in the introduction of negative numbers to avoid the confusion that often arises between the addition of negative seven and subtraction of positive seven.

Figure 4 shows a number line with a number of named points and some points to which no number has been assigned. Give a name to each of these points.

Question 4

FIGURE 4

ADDITION ON THE NUMBER LINE

Suppose a child has measured two lengths and recorded the measurements as 2.8 centimeters and 3.6 centimeters. You ask him, **What is the sum of these two lengths?** One way he can find the answer is by addition, using the number line. He can also learn to add negative and positive numbers using the number line. Consider two easy examples (Figure 5) and then see if you can add other pairs of numbers on the number line.

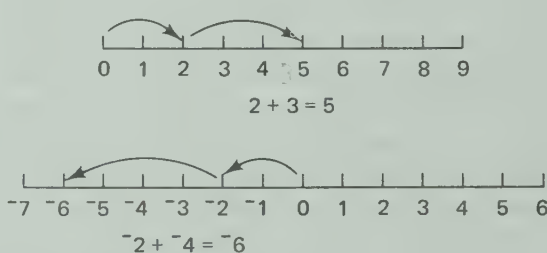


FIGURE 5

Now, return to the original example in which you ask the child to add 2.8 and 3.6. In Figure 6, the number line is marked in units of 0.2. There is no particular problem in drawing the arrow representing 2.8, but children may have difficulty in drawing the second arrow. You may count the three units first and then the 0.6, or the other way around. The sum of 2.8 + 3 is shown by the dotted arrow; the sum you are seeking by the right hand solid arrow is

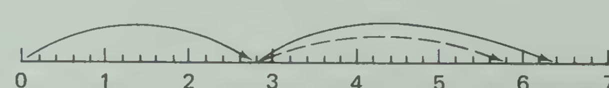


FIGURE 6

$$2.8 + 3.6 = 6.4.$$

Figure 7 shows the sum of 5 and $^{-}7$ is equal to $^{-}2$. Why is the upper arrow pointed to the left? (To represent $^{-}7$ as distinct from 7.)

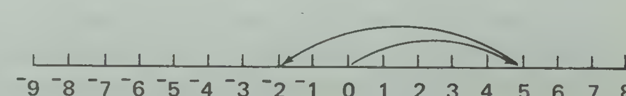


FIGURE 7

You may wish to try a few more of these examples before checking your competencies using the *Self-Evaluation.*

Activity 2—Dividing To Find Rates and Means

In the first part of this exercise, you added numbers using the number line. Generally, in this program, children will not need to add, subtract, or multiply numbers before they have acquired some skill in these operations in their mathematics class. However, this is not true for division. Finding rates and finding means play such an important part in science that a third-grade child who cannot divide by a one-digit number will be handicapped in his study of science. Below are two suggested methods for introducing division to your children.

A. For children who can name the product of any two whole numbers from zero to ten, treat division as the inverse of multiplication.

To divide 72 by 8, ask, How many 8's are there in 72? or, $\square \times 8 = 72$.

To divide 75 by 8, ask a similar question. Assist if necessary, by saying that there are nine 8's in 72 and ten 8's in 80. In 75, there are between nine and ten 8's.

To divide 144 by 8, write $\square \times 8 = 144$. Suggest that the children divide by thinking somewhat as follows: Ten 8's are 80.

$$\begin{array}{r} 144 \\ -\ 80 \\ \hline 64 \end{array}$$

How many 8's are there in 64? (Eight.) Hence, in 144 there are (ten + eight) 8's or eighteen 8's.

B. For children who are still having trouble with multiplication, introduce division by repeated subtraction.

To divide 72 by 8, subtract eights as follows:

$$\begin{array}{r} 72 \\ -\ 8 \\ \hline 64 \\ -\ 8 \\ \hline 56 \\ -\ 8 \\ \hline 48 \end{array} \qquad \begin{array}{r} 48 \\ -\ 8 \\ \hline 40 \\ -\ 8 \\ \hline 32 \\ -\ 8 \\ \hline 24 \end{array} \qquad \begin{array}{r} 24 \\ -\ 8 \\ \hline 16 \\ -\ 8 \\ \hline 8 \\ -\ 8 \\ \hline 0 \end{array}$$

How many 8's were subtracted? (Nine.) This is slow, but good practice.

FINDING RATES

A ratio or a rate is an expressed quotient. For example, if

a car travels 150 kilometers in 3 hours, the average rate of travel is $\frac{150}{3}$ kilometers per hour. Usually this number means more to children if it is written in equivalent form, 50. Thus, when rates are studied, division becomes a convenience. It is never a necessity, but results will be more readily interpreted and compared by the children if they can perform simple division.

Figure 8 shows the growth of bean seedlings over a seven day period. Notice that the growth for the first three days was 52 millimeters. The greatest daily growth took place between days 3 and 4. What is the average rate of growth in millimeters per day during the

Day	Mean height of seedlings, in millimeters
0	0
1	20
2	30
3	52
4	83
5	104
6	117
7	139

FIGURE 8

first three days? $\left(\frac{52}{3} = 17.3\right)$

last three days? $\left(\frac{139-83}{3} = \frac{56}{3} = 18.7\right)$

seven days? $\left(\frac{139}{7} = 19.9\right)$

In this example, the number of units of growth is divided by the number of days to find the rate of growth. The questions above are similar to problem situations in which children need to find rates.

Remember that a rate involves the ratio of a change in the measurement of some quantity other than time (such as distance, length, or temperature) and the change in time required for the change in the object. A rate is a ratio, and a ratio could always be interpreted as a rate. Do not make something mysterious about ratio. One good way to introduce ratio to children is to use the term interchangeably with rate in early experiences of the children with rates.

Here are two other problems involving rates:

A. Some children turned a bicycle upside down and started the front wheel rotating freely. They marked a point on the bicycle tire so that they could count the number of rotations of the wheel. One group counted 17 rotations in 8 seconds, and another group counted 25 rotations in 9 seconds. Which time was the wheel rotating faster?

$\frac{17}{8}$ is a little more than 2 rotations per second.

$\frac{25}{9}$ is almost 3 rotations per second.

The second wheel is rotating faster.

When children are able to express quotients to the nearest tenth, these results should be written as:

$$\frac{17}{8} = 2.1 \qquad \frac{25}{9} = 2.8$$

B. In a certain chemical reaction, bubbles are produced and can be counted to measure rate of reaction. Figure 9 shows the data recorded by one group of children. Ten bubbles were produced during the first ten seconds, 16 bubbles were produced during the next ten seconds, and so on. What is the rate of bubble production during the first ten seconds? During the first twenty seconds? During the first thirty seconds? During the last 20 seconds? In what ten second interval was the rate the greatest?

Number of seconds	Total number of bubbles	Number of bubbles in 10-second intervals
0	0	
10	10	10
20	26	16
30	50	24
40	86	36
50	126	40
60	168	42

FIGURE 9

Question 5

FINDING THE MEAN

In science investigations, an individual child or groups of children will make and record many measurements. There may be measurements of length, mass, time, force, temperature, or volume. They soon learn that no matter how careful they are, if they repeat a measurement, they do not always get the same value. Differences may result from their own lack of care, from differences in the measuring instruments, from differences in the children making the measurements, and sometimes from differences in the object or objects being measured. Suggest that they find the mean of the measurements made and use the mean as the measured length. The mean is a number which is representative of numbers in the set of data under consideration. To find the mean, add the numbers in the set and then divide by the number of numbers in the set.

Suppose you ran five tests. In each test, you added one gram of anhydrous copper sulfate to 10 milliliters of water and measured the increase in temperature. You tried to keep all of the conditions the same each time you ran a test. Your data are recorded in Figure 10. What is the average temperature increase for the five trials? The number you obtain represents the amount of rise in temperature you would expect each time you make the investigation under the circumstances described. This kind of average is called the *arithmetic mean,* or for our purpose, the *mean.*

Question 6

Test number	Increase in temperature of the water, in degrees Celsius
1	8.2
2	8.5
3	7.7
4	8.2
5	7.9

FIGURE 10

By the time the mean is introduced in *Science—A Process Approach,* the children should be able to add sets of numbers involving six addends and probably more. You may have to assist them with the division. Of course, you will not need to ask them to find the quotient to the nearest tenth before the fifth or sixth grade.

One way to help the children see why the mean is a representative number is to use the number line in a manner illustrated in Figure 11. The numbers in the set are represented by the black dots. Each arrow above the number line represents the distance one number is to the left or to the right of 8.1 (the mean).

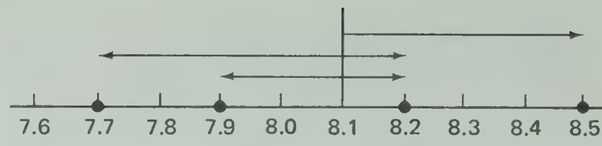


FIGURE 11

	tenths
left distances	2, 4
right distances	1, 1, 4

The sum of right distances is the same as the sum of left distances. Distances from the mean are called *deviations* from the mean. If your children have some facility with the addition of negative and positive numbers, the deviations on the left can be expressed as negative numbers; then the sum of the deviations can be found, as shown in Figure 12. The sum of the deviations from the mean is zero, if the actual mean is used. If an approximate mean is used, the sum of the deviations will, of course, not be exactly zero.

Number	Deviations from 8.1
8.2	+0.1
8.5	+0.4
7.7	$^{-}0.4$
8.2	+0.1
7.9	$^{-}0.2$
Sum	0

FIGURE 12

The *mean* is one of the three most common kinds of representative numbers. For different sets of data, you might choose the *median* or the *mode,* instead of the *mean,* to represent a set of numbers. *Median* is introduced in the exercise *Precision in Measurement, Interpreting Data 3, Exercise o,* Part E, and *mode* is also defined in the *Rationale* of that exercise, although it is not used in this program. For a discussion of when you might use one or the other of these three terms, see that exercise.

COMMENTS ON ACTIVITIES

ACTIVITY 1 (QUESTION 1)

8.3, 8.4, 8.6, 8.7, 8.8

ACTIVITY 1 (QUESTION 2)

8.41, 8.43, 8.45, 8.46, 8.47, 8.48

ACTIVITY 1 (QUESTION 3)

8.481, 8.482, 8.483 ... 8.489

ACTIVITY 1 (QUESTION 4)

Diagram of Figure 4 – filled in

ACTIVITY 2 (QUESTION 5)

(a) 1 bubble per second is produced during the first 10 seconds
(b) 1.3 bubbles per second
(c) 1.7 bubbles per second
(d) 4.1 bubbles per second

ACTIVITY 2 (QUESTION 6)

$$\frac{8.2 + 8.5 + 7.7 + 8.2 + 7.9}{5} = \frac{40.5}{5} = 8.1$$

(The average temperature increase is 8.1 degrees Celsius.)

SELF-EVALUATION

1. On the line shown in Figure 13 mark points and name them for the following numbers: 0, 1, $^-1$, $^-5$, 3.5, 2.6
2. Write the number names of the points corresponding to the arrows in Figure 14. In F and G estimate the number to the nearest tenth.
3. Record the measurements in (a), (b), and (c), and in (d), the shaded area in square centimeters. (See Figure 15.)

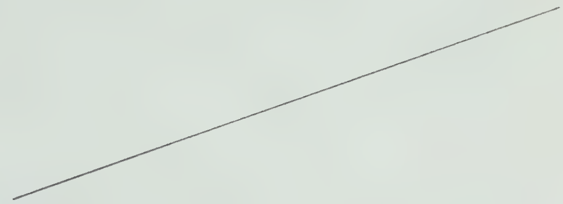
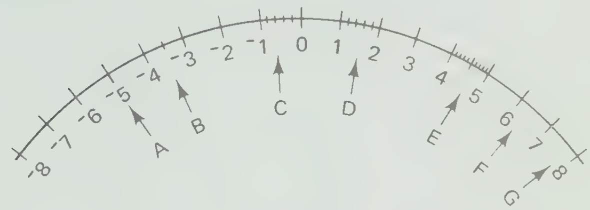
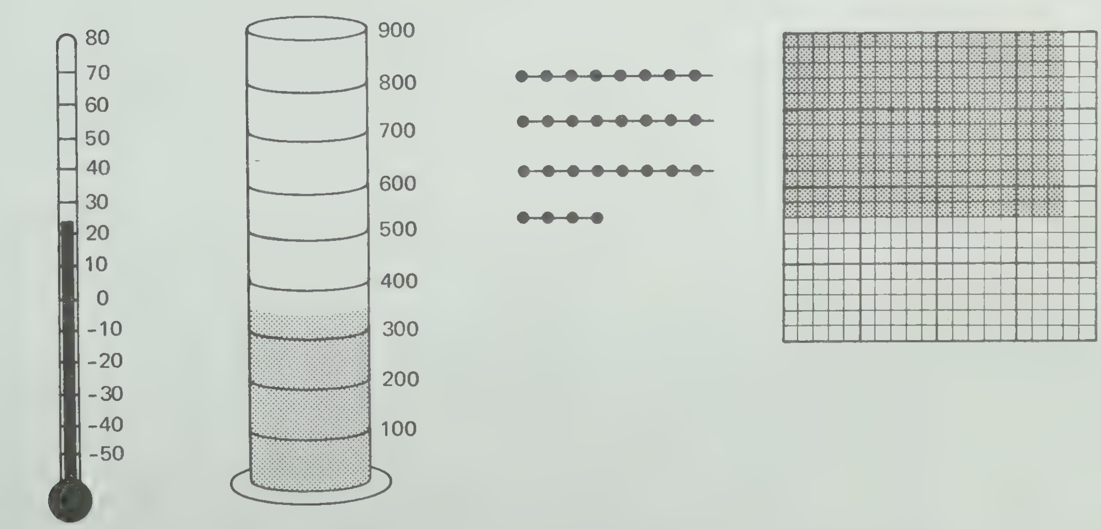


FIGURE 13



A____ B____ C____ D____ E____ F____ G____

FIGURE 14



Celsius thermometer (a) ______

Cylinder, graduated in ml (b) ______

Beads in units of ten beads = 1g (c) ______

Grid (d) ______

FIGURE 15

4. Add the following numbers, using the number line shown in Figure 16. Draw arrows to indicate how you apply the rule for adding numbers using the number line.
(a) 2.4 + 3.9, (b) $^-3 + 7$

5. In Examples (a) and (b) find the mean of the two sets of numbers.

(a) 5, 10, 15, 20, 50, 45, 40, 35, 30, 25, 20
(b) Five children poured the contents of a small container of water into a graduated cylinder and recorded the amount of water in milliliters as follows.

Child	Number of milliliters
A	20
B	21
C	18
D	24
E	22

FIGURE 16

6. Three Olympic champions of the 800-meter run made these times:

(a) 109.2 seconds
(b) 107.7 seconds
(c) 106.3 seconds

What was the rate of each runner per 100 meters? What was their mean rate per 100 meters?

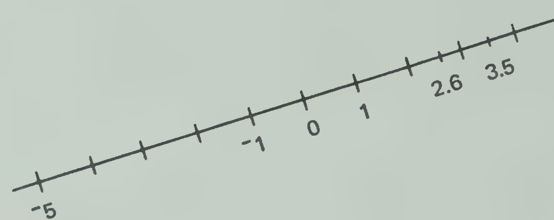


FIGURE 17

COMMENTS ON SELF-EVALUATION

1. See Figure 17.
2. A $^-5$ D 1.6   G 7.7
B $^-3.5$ E 4.6
C $^-0.6$ F 6.3
3. (a) 24°C   (b) 35 ml   (c) 3.4 g   (d) 8.64 cm^2

Note on 3(d): Each box is 2 millimeters on a side and the rule for area is length times width. The length measures 36 millimeters and the width measures 24 millimeters. 36 x 24 = 864 square millimeters or 8.64 square centimeters

4. See Figure 18.
5. (a) Mean, 26.8   (b) Mean, 21
6. Rate per 100 meters:

(a) 13.65 seconds; (b) 13.46 seconds; (c) 13.29 seconds. Mean rate per 100 meters is 13.43 seconds.

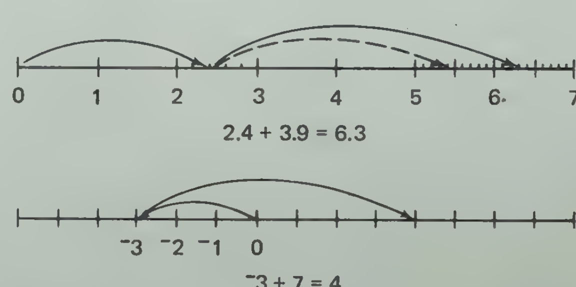


FIGURE 18

MEASURING

OBJECTIVES

After you have studied this exercise you should be able to

1. *DEMONSTRATE* the use of simple measuring instruments to measure length, mass, and time.
2. *APPLY RULES* for calculating derived quantities from two or more measurements.
3. *DISTINGUISH* between accuracy and precision.
4. *CONSTRUCT* estimates of simple measurements of quantities such as length, area, volume, and mass.

RATIONALE*

"When you cannot measure it, when you cannot express it in numbers,—you have scarcely, in your thoughts, advanced to the stage of Science, whatever the matter may be."—Lord Kelvin.

There is much in science that can be learned without measuring, and most scientists would agree that Lord Kelvin overstated the case. However, they would also agree that measuring is one of the skills that is essential for most scientific investigations. You will find it is a fundamental skill that is used throughout *Science—A Process Approach,* both in the *Measuring* exercises and in exercises from all other processes as well.

Skill in measuring requires not only the ability to use many measuring instruments properly, but also the ability to carry

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*The metric system of units of measurement is used exclusively in *Science—A Process Approach,* and, therefore, throughout this paper. If you are not familiar with the metric system, read the background paper on that subject before proceeding further.

out calculations with those measurements. In addition, it requires judgment about the appropriate instrument to use for making a measurement (a meterstick is more appropriate than a 30-centimeter ruler for measuring the length of a room), and about when approximate measurements can be used instead of precise ones.

Thousands of types of measuring instruments are used in scientific investigations. The instruments range from simple ones like a ruler to complex and expensive ones like a mass spectrometer. In *Science—A Process Approach,* measurements are made with simple instruments such as rulers, springs, and thermometers.

In Part A, children learn the fundamentals of measuring by comparing the lengths of paper strips. Measurements are expressed in terms such as "smaller than," and "larger than." Later, the children discover the need for a standard unit of measure. They use standard units such as centimeters and meters for linear measurement and then they use milliliters and liters to measure volume. In Parts D and E, the children learn to measure force using the newton as the standard unit.

Figure 1 shows how some quantities may be measured. Note that for items 1-8, each measurement is made with a single instrument, and no computations are required. For items 9-11, the measurements are also made with a single instrument, but a mathematical operation is required to obtain the desired measure. Measurements of this type are sometimes called *indirect measurements.*

Measurements of speed, density, and heat (items 12-14 in Figure 1) are examples of *derived quantities.* Note that to obtain measures of each of these quantities, two measuring instruments are used, and mathematical operations are carried out to obtain the measure of the quantity. The units in which derived quantities are expressed may be called *derived units.* For the derived quantities listed in Figure 1, the derived units are: centimeters per second for speed, grams per milliliter for density, and calories (degrees Celsius per milliliter of water) for heat. Other derived units in the metric system may be used for each of these quantities. The unit that is appropriate depends on what is being measured. The speed of an automobile, for example, is usually measured in the derived unit kilometers per hour, rather than in centimeters per second.

Although the difference is not stressed in *Science—A Process Approach,* it is important for your own background in measurement procedure and reporting to distinguish between the terms *precision* and *accuracy.** *Precision* refers to the agree-

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*See also the *Rationale* in *Precision in Measurement, Interpreting Data 3, Exercise o,* Part E.

Quantity measured	Measuring instrument	Operation performed	Computation	Unit
1. Length	Ruler	Read scale	--------	centimeter (cm)
2. Area	Grid	Count squares	--------	square centimeter (cm^2)
3. Volume of a liquid	Graduated container	Read scale	--------	milliliter (ml)
4. Angle	Protractor	Read scale	--------	degree
5. Temperature	Thermometer	Read scale	--------	degree Celsius ($^\circ C$)
6. Time	Stopwatch	Read scale	--------	second
7. Force	Spring scale	Read scale	--------	newton (n)
8. Mass	Equal-arm balance	Count standard masses	--------	gram (g)
9. Area of a rectangle	Ruler	Read scale	Multiply length	cm^2
10. Volume of a rectangular prism	Ruler	Read scale	Multiply length, width and height	cubic centimeter (cm^3)
11. Volume of an irregular solid	Graduated container of water	Read scale, put object in the water and read scale again	Subtract initial from final scale reading	cubic centimeter (cm^3)
12. Speed	Ruler and stopwatch	Read scale of ruler read scale of stopwatch	Divide distance traveled by time elapsed	cm/sec
13. Density of a solid	Equal-arm balance and graduated container of water	Count standard masses measure volume as described in 11.	Divide mass by volume	g/cm^3
14. Heat	Graduated container of water and thermometer	Read scale of container read scale of thermometer before and after changing the temperature of the water	Subtract initial from final temperature multiply temperature change by volume of water	calorie ($^\circ C$/ml of water)

FIGURE 1

ment among observed values in repeated measurements. Obviously, if you were to measure the length and width of your classroom by using a meterstick and were to record your results to the nearest millimeter, you would likely not record the same figure each time. You would, however, be able to report a *range* of values and could with some confidence say that the length or width of the room was a certain value, plus or minus a certain number of millimeters, depending on your techniques in using your meterstick. The smaller the range the greater is the precision of your measurement.

Accuracy, on the other hand, refers to the agreement of the observed measurement with the *actual* or *true* value. Actual or true value might be defined operationally as the measurement that is made as carefully as possible with the best measuring instrument that can be made. Accuracy is affected both by the care with which a measuring instrument is used and by the nature of the instrument. For example if the scale on your meterstick was a bit longer or a bit shorter than a meter, your measurements would not be accurate, even though they might have high precision. Not only are scientists interested in improving the accuracy of their observations, but their ultimate aim is to devise instruments and techniques that will decrease the possible errors (precision) and also be as close as possible to the true value (accuracy).

It is also important in scientific work to use judgment in deciding when to measure precisely and accurately and when to make approximations. An example of a situation in which approximate measurements are satisfactory is found in the exercise, *Two Common Gases, Defining Operationally 7, Exercise a,* Part G, where a tablespoon is an adequate measure of 15 grams of sodium bicarbonate, and a pile 5 millimeters square on the end of a paste stick is a sufficiently accurate measure of 100 milligrams of manganese dioxide.

Skill in measuring also includes the ability to estimate. The man who guesses your weight at the carnival is highly skilled in estimating weights. Most people do not develop much skill in estimating measurements. You should practice making estimations of length, area, volume, time, mass, and so on. There are many places in *Science—A Process Approach* where you can encourage your students to make estimations and approximate measurements.

Finally, you can make estimations to increase the accuracy of measurements. If you are using a thermometer that is graduated in degrees, and if the top of the liquid column is midway between 25° and 26° on the scale, you can estimate that the temperature is 25.5°. Assuming that the scale on the thermometer is properly calibrated—that is, the scale records the true value of temperature—the measurement of 25.5° is more accurate than a measurement of 25° or 26°. Scientists usually try to estimate to the nearest tenth of the smallest scale division of an instrument they are using to make a measurement. With practice, you should be able to do this, too.

VOCABULARY

accuracy
derived quantity
precision
derived unit
estimate

MATERIALS

Meterstick, 1
30-cm ruler, 1
Graduated container, 100-ml, 1
Vial, 30–50 ml, 1
Spring scale, 1 newton per cm, 1
Graph paper, 1 sheet
String, 2 meters
Washer, 4–5 cm diameter, 1
Stopwatch, watch, or clock with second hand, 1
Test tube, 15-ml, 1
Wooden dowel, 0.5 x 10 cm, 1

Activity 1—Precision in Measuring with Simple Instruments

Use a meterstick, graduated in millimeters, to measure something that is more than one meter long; a table top, a chalkboard tray, or a window ledge will be satisfactory. Measure carefully and record your measurement to the nearest millimeter. Repeat the measurement until you have done it ten times. What is the mean of your ten measurements?* What is the range of your measurements?**

The *precision* of a set of measurements is sometimes expressed by writing the mean of the set followed by a number that indicates the range of the set. Take the following set of measurements as an example.

25 cm, 23 cm, 28 cm, 22 cm, 25 cm, 26 cm, 25 cm, 22 cm, 24 cm, 26 cm.

The mean of the set is 25 centimeters. The range of the set is 6 centimeters. One way to show the precision of the measurement that is best representative of the group is to write the measurement as follows:

25 ± 3 cm, where $\pm$ is read "plus or minus."

This is, of course, a special case. The mean falls at the midpoint of the range. If the mean is not at the midpoint of the range, we may arbitrarily indicate the precision as the mean $\pm$ one half the range. For example, if a set of measurements ranged from 48 to 56 and the mean was 50, the measurement would be written as 50 ± 4. Scientists have a somewhat more complicated method of using the range to indicate precision, but the rule just stated will be satisfactory for our purposes.

Write the mean of your set of measurements and show the precision of the measurements by applying the above rule. Question 1

Use a 100-milliliter graduated container to measure the volume of a vial that has a volume between 30 and 50 milliliters.

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*Just a reminder of how to find the mean of a group of numbers. Add all the numbers and divide the sum by the number of numbers.

**To find the range, subtract the lowest number in the set from the highest number.

One way to do this is to fill the vial with water and then carefully pour the water from the vial into the graduated container. Repeat this several times. What are the mean and the precision of your measurements?

Question 2

Measure the force that is required to make a book start sliding across a smooth surface. Use a spring scale graduated in newtons (a spring that stretches 1 centimeter for every newton of force applied is satisfactory). Fasten the end of the spring to the book with a large paper clip or a binder clip. Pull on the spring scale and note the position of the indicator on the scale at the instant the book starts moving. Make ten measurements and determine the mean and the precision of your measurements.

Question 3

There are various ways of measuring areas. If the area is regular, such as that of a rectangle, the area may be calculated from linear measurements. Measure the length and width of the object and then multiply; the product is the area. If the area is irregular, place the object on a grid, draw around it, and count the number of squares that are included within the outline of the area. Establish a rule for deciding whether or not to count squares through which the boundary of the area passes. One useful rule is to count squares if more than half the area of the square appears to be within the boundary of the area and not to count squares if less than half the area appears to be within the boundary of the figure.

Draw an irregular figure on an index card. Cut it out, place it on a piece of 2-millimeter graph paper and draw around it with a sharp pencil. Count the number of squares within the outline of the area, using the rule stated above for deciding whether or not to count part-squares. It may help you keep track of your count if you divide the area within the figure into rectangles, as in Figure 2. The sum of the areas is 507 squares. To get some idea of the precision of this sort of measurement, outline the figure on graph paper two more times. Then count squares again for each outline. How well do the three measurements agree?

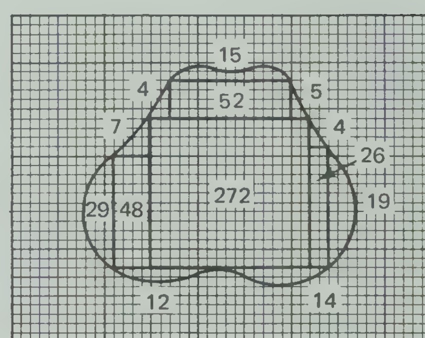

FIGURE 2

Activity 2—Measuring Mass with an Equal-Arm Balance

The mass of an object is commonly measured by comparing it with standard masses on an equal-arm balance, shown in Figure 3. Examine a balance from your equipment kit. Note that the pans can swing freely, and that at the center of the beam there is a knife-edge that rests in a slot. The beam can swing like a teeter-totter. When there are no objects in the pans, the pointer at the center of the beam should be at the center of the scale.

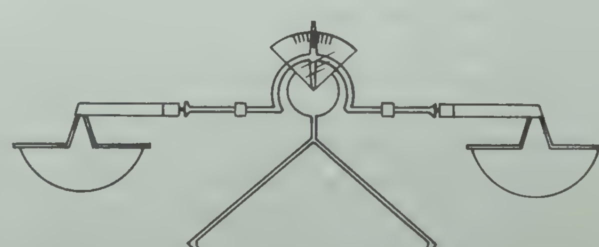

FIGURE 3

Now, place an object in the left-hand pan.* What happens? That end of the beam goes down until it rests on the table top. Why does it do this? Because earth-pull (or gravitational force) is greater on that end of the pan than on the other. We could illustrate this with vectors, as in Figure 4. Now, place standard masses in the right-hand pan until the pointer has returned to the center of the scale. Draw a diagram to show the forces acting on the two pans now. What is the mass of the object in the left pan? Its mass is the same as the sum of the standard masses in the right-hand pan.

Question 4

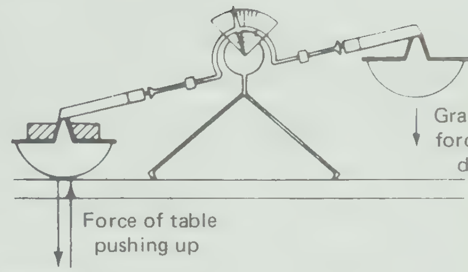

FIGURE 4

Activity 3—Calculating a Derived Quantity

Rate is one of the most commonly used derived quantities. The rate with which you are probably most familiar is the speed of an automobile. This is expressed in miles per hour in the United States and in kilometers per hour in most of the rest of the world. The two measurements from which *speed* is calculated are *distance* and *time.* Measurements other than distance are sometimes used for calculating rates. For example, pulse rate is expressed as beats per minute, and the rate of oscillation of a pendulum as swings per minute.

Make a pendulum from a piece of string and a large washer. Support it from a table, a shelf, or a door frame. Adjust the length of the string so that the pendulum is one meter long. Hold the pendulum bob 15 to 20 centimeters to one side and let it go. Measure the number of seconds it takes for the pendulum to make 10 swings (over and back). If you have a stopwatch, you can make the measurement easily by yourself. If you use a watch or clock with a second hand, you will need to have someone help you measure the time while you count. Repeat the measurements several times. What is the mean time required for ten swings? From the mean time for ten swings, calculate how many swings the pendulum makes in one minute.

Question 5

Does the length of the pendulum affect the rate at which the pendulum swings? Try it. Calculate the rates in number of swings per minute.

Question 6

Activity 4—Accuracy

The accuracy of a measurement is influenced by the measuring instrument. Use the scale shown in Figure 5 to measure the width of a dollar bill to the nearest millimeter.

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*This is standard practice among scientists, probably because it is easier for a right-handed person to put standard masses in the right-hand pan—and the majority of people are right-handed. If you are left-handed, and want to put the object in the right pan and the standard masses in the left, that is perfectly all right.

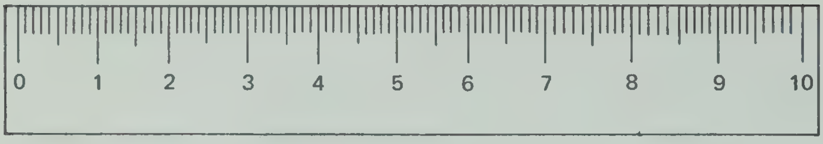

FIGURE 5

Next, use your 30-centimeter ruler and measure the same dollar bill to the nearest millimeter. Do the measurements agree? Were the two measurements made with equal precision? Examine both scales and then state which measurement you think was the more accurate. Explain why you think one measurement is more accurate than the other.

Activity 5—Estimating Measurements

Skill in estimating can be developed only by continual practice. You will probably find that you are not very skillful in estimating the measurements suggested in this activity, but with practice, you should improve.

Use rough standards in making your estimated measurements. For example, the width of one of your fingernails may be approximately 1 centimeter, the width of your hand about 1 decimeter, and your normal pace (one step) about 0.75 meter. You can estimate time in seconds by counting slowly—one steamboat, two steamboats, three steamboats—and this will give you approximate time in seconds. You can use your box of exercises for *Science—A Process Approach* as a rough standard of mass; it weighs about 1 kilogram. For smaller masses, a nickel is a good standard; it weighs 5 grams.

The following are suggestions of some quantities that you might estimate. After you have made each estimation, make the measurement with the appropriate instrument to find out how close your estimate was to the true measure of the quantity.

1. The length and width of a room, in meters
2. The area of the floor, in square meters
3. The volume of a cup, in milliliters
4. The mass of a book, in kilograms
5. The length of time it takes to fill a glass with water from a slowly running faucet

COMMENTS ON ACTIVITIES

ACTIVITY 1 (QUESTIONS 1, 2, 3)

How precise were your measurements? If the range is large, how much confidence would you have in your measurements? Would you measure again?

ACTIVITY 2 (QUESTION 4)

Does your diagram look something like Figure 6? It should.

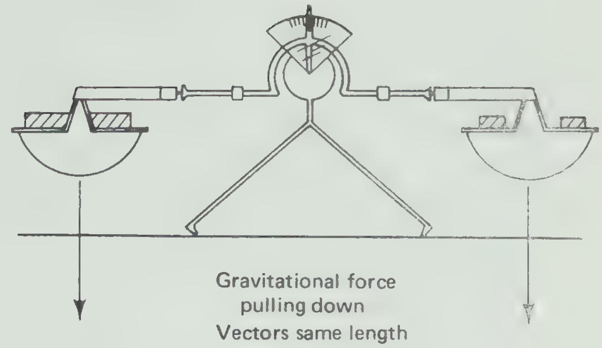

FIGURE 6

ACTIVITY 3 (QUESTION 5)

The number of swings per minute increases as the pendulum is made shorter.

ACTIVITY 4 (QUESTION 6)

The scale in the book is inaccurate in the following places: Between 1.5 and 2.0 centimeters, between 3.5 and 4.0 centimeters, and between 5.5 and 6.0 centimeters the scale is short (4 instead of 5 millimeters). Between 7.0 and 7.5 centimeters, between 8.0 and 8.5 centimeters, and between 9.5 and 10.0 centimeters the scale is too long (6 instead of 5 millimeters).

SELF-EVALUATION

1. Figure 7 is a picture of a box.

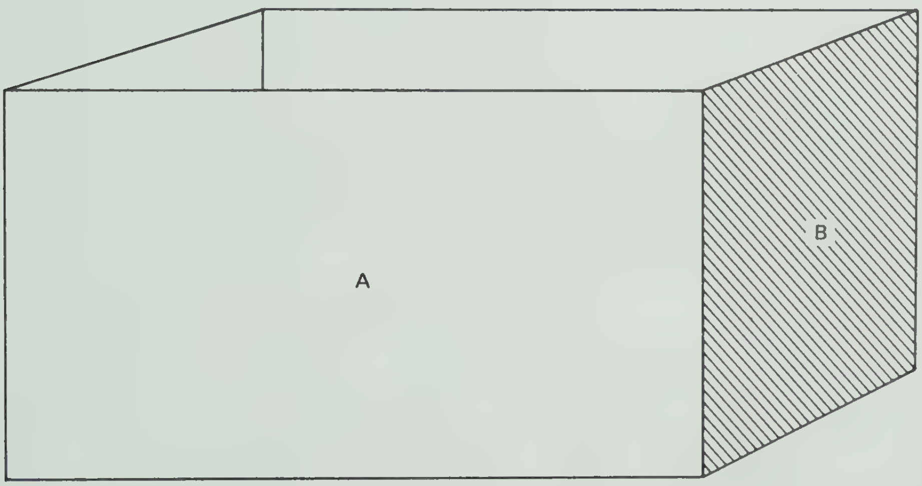

FIGURE 7

(a) Estimate the area of side *A*.
(b) Next, measure the length and height of the box and calculate the area of side *A*. Remember, to find the area of a rectangle, find the product of the length and width. To find the volume of a rectangular solid, measure the length, width, and depth, and find the product of the three measures. The product is the volume.
(c) The end of the box is square. What is the volume of the box?

2. The density of a wooden dowel may be measured indirectly by taking the ratio of the length below water (when the dowel is floating in an upright position, as in Figure 8) to the total length of the dowel. Use a 15-centimeter test tube and a wooden dowel and measure the density of the dowel. (See background paper on *Density.*)
3. Two pupils measured the diameter of a circle, as in Figure 9, along each of the diameters indicated. Pupil *A* recorded the following measurements:

   72 millimeters
   73 millimeters
   71 millimeters
   74 millimeters

   Pupil *B* recorded the following measurements:

   69 millimeters
   70 millimeters
   70 millimeters
   69 millimeters

   Comment on the precision and accuracy of the two sets of measurements.

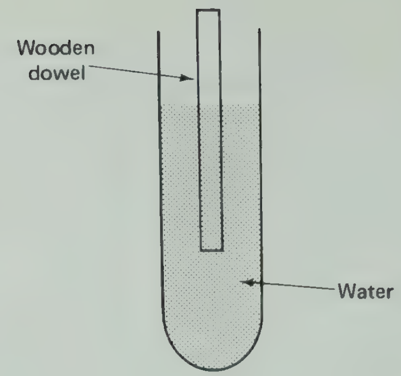

FIGURE 8

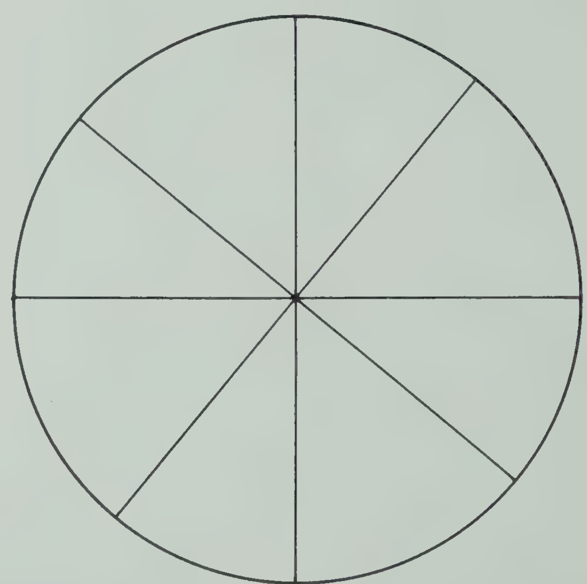

FIGURE 9

COMMENTS ON SELF-EVALUATION

1. (a) Are you becoming more proficient at estimating area?
   (b) The side of the box is 9 centimeters long and 5 centimeters high, so the area is 45 square centimeters.
   (c The width of the box is 5 centimeters (since the end of the box is square and the height is 5 centimeters). The volume of the box is 225 cubic centimeters.

2. Floating objects sink into water until the *mass* of water displaced is the same as the *mass* of the object itself (Archimedes' principle). The *volume* of water displaced is the same as *the volume* of the object that is under water. For a regular object, such as a dowel, the *volumes* of any two portions are proportional to the *lengths* of the portions. So the *length* of the portion below the water is proportional to the *volume* of water displaced. Since the density of water is one gram per cubic centimeter, the mass of the floating object, in grams, is the same as the volume of water displaced, in cubic centimeters.

   And so:

$$\frac{\text{length of dowel under water}}{\text{total length of dowel}} = \frac{\text{mass of dowel}}{\text{volume of dowel}}$$

and

$$\frac{\text{mass of dowel}}{\text{volume of dowel}} = \text{density of dowel}$$

Different kinds of wood have different densities. Many range from 0.65 to 0.85 gram per cubic centimeter. (See background paper on *Density*.)

3. The measurements made by Pupil *A* varied from 71 to 74 millimeters, a range of 3 millimeters. Pupil *B*'s measurements (range, 1 millimeter) were more precise than *A*'s. However, if you measured the diameters with your ruler (and if your ruler was accurate), you should have found that *A*'s measurements were more accurate than *B*'s. (The diameter of the circle is 73 millimeters.)

COMMUNICATING

OBJECTIVES

After you have studied this exercise you should be able to

1. *DESCRIBE* the properties of an object in sufficient detail so that another person can identify it.
2. *DESCRIBE* changes in the properties of an object.
3. *CONSTRUCT* a map to show the relative positions and sizes of objects, and *IDENTIFY* objects and distances on a map.
4. *CONSTRUCT* a bar or point graph of number pairs obtained from measurements.
5. *DESCRIBE* verbally the relationships and trends shown in a graph.

RATIONALE

Communicating is a process not only of science but of all human endeavors. Clear, precise, unambiguous communication is desirable in any activity, and is fundamental to all scientific work. Scientists communicate with oral and written words, diagrams, maps, graphs, mathematical equations, and various kinds of visual demonstrations.

In *Science—A Process Approach* the *Communicating* process begins with oral communication. The children practice describing objects so that they can be identified by other children. Most children find this fun and enjoy doing it. Next, the children learn to describe objects whose properties are changing. For example, they describe butter melting or water evaporating. This is more difficult, both for children and adults, than describing objects that do not change. But it is an important skill and should be practiced whenever an opportunity occurs.

Later in the *Communicating* process, the children use diagrams to communicate change, as in *Using a Sundial to Describe Shadow Changes, Communicating 9, Exercise r,* Part C.

Maps, diagrams, and graphs are also used for communication in *Science—A Process Approach.* Since graphs are used so frequently in scientific communication, the children are given frequent opportunities to construct and interpret graphs of data they collect in their investigations.

As you will see in the next process exercise, *Predicting,* there is a close connection between communicating with graphs and making predictions from graphs. This close connection is also shown on the Hierarchy Chart where the *Communicating* and *Predicting* processes are combined into a single hierarchy of behaviors.

Although there are only thirteen exercises in the *Communicating* sequence, every exercise in the program requires the children to communicate in one way or another. This is evident from the objectives of the exercises. For example, whenever the children *name* or *describe* an object or an event, or *construct* a graph, they are developing skills in communicating.

This exercise discusses the various methods scientists use to communicate as precisely as possible. Can you describe an object accurately enough so that it can be distinguished from a group of similar objects? *Activity 1* helps you sharpen your skills in precise communication. Can you describe an object when it is constantly undergoing a change? In *Activity 2,* you will be asked to describe the changes that take place in a burning candle. Another important way to communicate is with maps. Practice in using and constructing maps is provided in *Activity 3.* The last activity, *Activity 4,* discusses the use of bar and line graphs. Because graphing is used extensively throughout this program, it is important that you fully understand graphing procedure. Even if you are confident about your graphing skills, be sure to check the section on graphing conventions used in *Science—A Process Approach.*

VOCABULARY

scale (of a map)
line graph
responding variable
continuous variable
number pair
y-axis
bar graph
manipulated variable
discontinuous variable
smooth curve
x-axis

MATERIALS

- Irregular paper shapes
- Small birthday candle
- 30-centimeter ruler
- Modeling clay or candle wax
- Stopwatch or watch with second hand
- Meterstick
- Pennies, nickels, dimes, quarters, half-dollars (optional), several of each
- Paper cup
- Pin
- Water
- 100-milliliter graduated container

Activity 1—Describing an Object

Question 1

Pick out one of the shapes in Figure 1, and describe it in sufficient detail so that another person could distinguish it from the four other shapes. Assume that these are irregularly shaped pieces of paper that can be moved around. For this reason, you should not use directions such as left, right, top, and bottom. Instead, practice describing the shapes by referring to straight sides, angles, and so on. Try to make your descriptions brief by giving the minimum of information needed to identify the object. You may want to write your descriptions. After you have made your descriptions, refer to the comments on this activity at the end of the exercise.

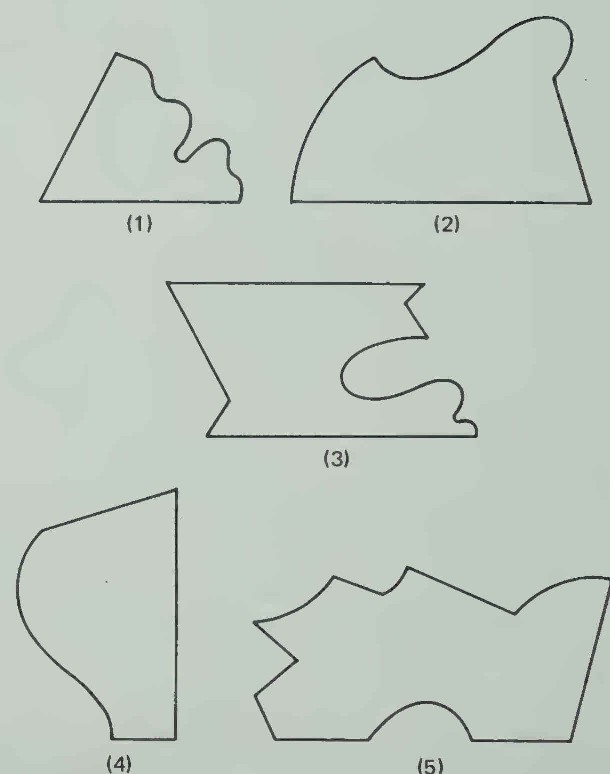

FIGURE 1

Next, cut five or six different irregular shapes from a piece of paper. Place these on a table and ask a friend to examine them while you describe one of them. Could he identify the shape from your description? Did you remember to keep your description as brief as possible?

Activity 2—Describing Properties that Change

It is more difficult to make precise observations of objects whose properties are changing than of objects whose properties are fixed. Nevertheless, describing changing properties is an important activity in scientific work, and you should practice making such descriptions.

Fasten a small birthday candle in a vertical position to a level surface with a drop of melted wax or a small piece of modeling clay. Make some observations of the candle before you light it. Then light it and make observations until it burns down and goes out. Since you will be observing properties that change with time, you should make rough time measurements (to the nearest minute). Since the length of the candle changes as it burns, you should make rough measurements of length. It may be helpful to make notes of your observations as you watch the candle burn, rather than waiting until it has burned completely. As you make your observations, remember to distinguish between observations and inferences.

Question 2

After you have written your description of the burning candle, read the description in the *Comments on Activities* at the end of the activities. Your description should be at least as complete as that one. If yours is more detailed, that is fine.

Activity 3—Communicating with Maps

Figure 2 is a map of the central part of Washington, D.C. The

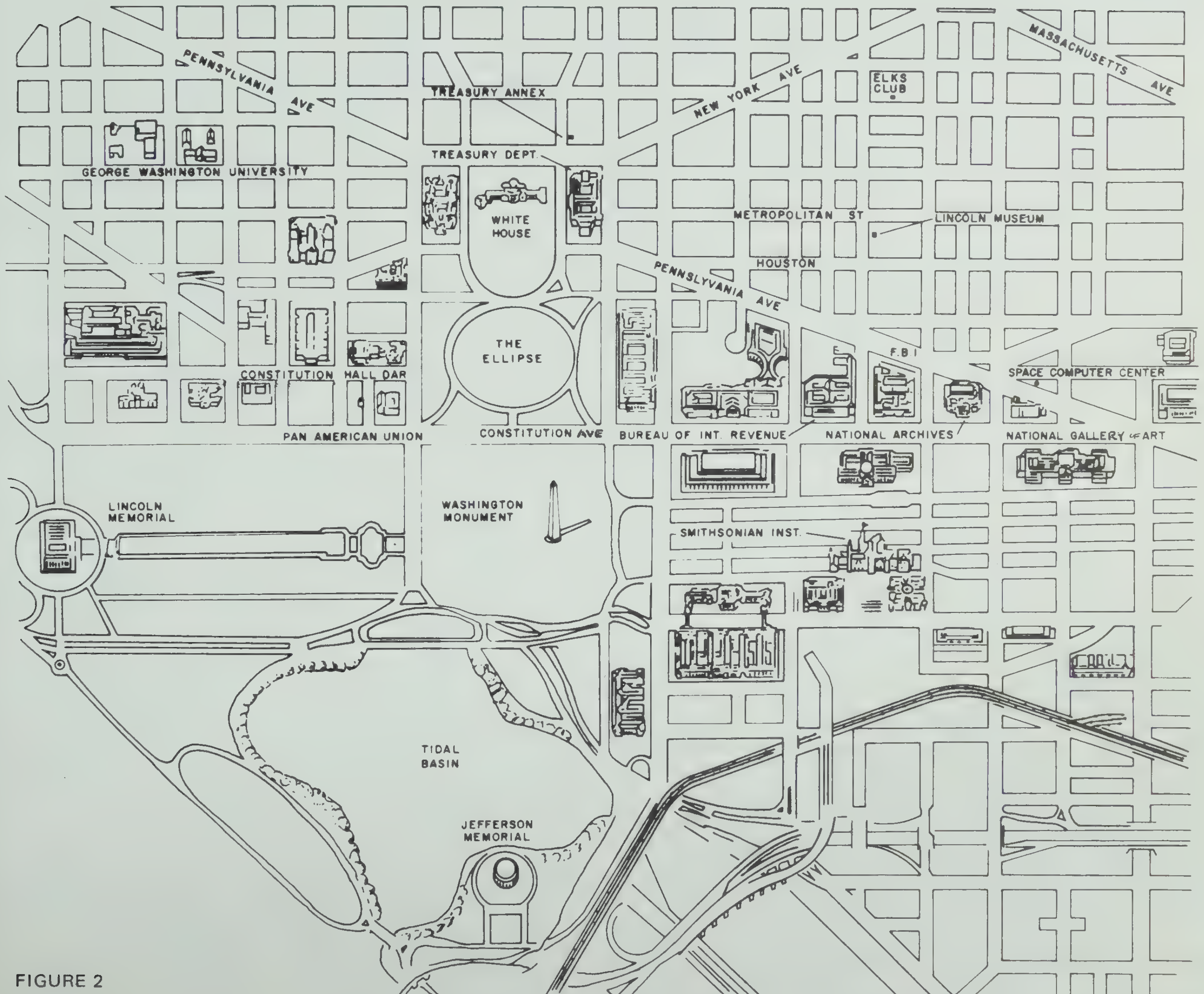

FIGURE 2

scale of the map is 5 centimeters per kilometer. Use the map and a 30-centimeter ruler to answer the following questions.

Question 3

(a) How far is it from the White House to the National Archives along Pennsylvania Avenue?
(b) What Memorial is approximately 2 kilometers directly south of the White House?
(c) How wide is the Tidal Basin at its widest point?
(d) Suppose that you are taking a walking tour of Washington. You start at the Lincoln Memorial, walk east to the Washington Monument, then north to the Treasury Department, then southeast along Pennsylvania Avenue to the National Gallery of Art. How far would you have walked?
(e) If your average rate of walking is 4 kilometers per hour, how long would it take you to walk this route?

Now that you have practiced using a map, try to construct one. Make a map of a room showing the location of several pieces of furniture. Use a meterstick to make the room measurements and a 30-centimeter ruler to draw the map. The scale you are going to use will depend on the size of the room and of the paper on which you draw your map. For example, if the room is 5 meters square and you use a scale of 3 centimeters to 1 meter, the map will be 15 centimeters square.

To make your map, first measure the length and width of the room, and draw the outline of the room to the scale you selected. Next, measure the doors and windows and indicate their positions on your map. Then measure the location and size of the pieces of furniture you want to show on your map. A convenient way to measure the location of pieces of furniture is shown in Figure 3.

First measure the shortest distance from one corner of the chair to the nearest wall. Then measure the distance from that point on the wall to the corner of the room. Do the same for another corner of the chair. With these measurements and measurements of the size of the chair, you can draw the size, location, and orientation of the chair on your map.

When you have completed your map, use it to estimate the distance between two pieces of furniture. Measure the distance on your map in centimeters and use the scale to convert the measurement to meters. Then use your meterstick to measure the actual distance between the pieces of furniture. Did your map communicate information accurately? It should, if you made your map carefully.

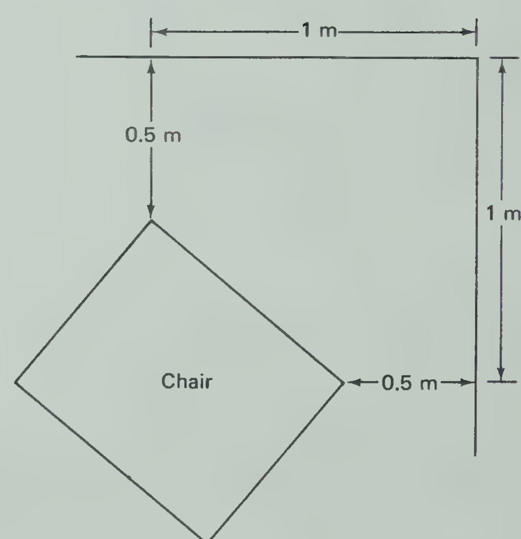

FIGURE 3

Activity 4—Bar Graphs and Line Graphs

A graph is a device for communicating a relationship between two variables. In *Science—A Process Approach,* pupils

are introduced to graphing with bar graphs which are particularly useful for recording numbers of different objects. For example, in one hour a bird watcher counted 20 sparrows, 6 robins, 2 cardinals, 1 wren, and 10 starlings. This information can be displayed in a bar graph, as in Figure 4.

Look at Figure 4 carefully and then make your own bar graph. Take some change from your coin purse and count the number of each kind of coin. Then make a bar graph to show the numbers of pennies, nickels, dimes, quarters, and half-dollars.

The two variables that are plotted in Figure 4 and the ones you have just plotted are called *discontinuous variables.* This means that there are no intermediate values of the variables between the values shown. For example, a bar showing 5.5 quarters would be meaningless since there is no such thing as half a quarter. Likewise there is no coin between a penny and a nickel, or between a nickel and a dime. Both the number of coins and the kind of coins are discontinuous variables. Bar graphs are useful for showing relationships between discontinous variables.

Line graphs, on the other hand, are useful for communicating relationships between *continuous variables.* Figure 5, for example, shows the number of swings per minute for pendulums of different lengths. The points with the circles around them show the number pairs that were actually measured. Here the two variables are continuous. There are intermediate values between the points that are plotted. The pendulum can be of any length and there can be any number of swings per minute including fractions of swings such as 30.3. The smooth curve through the points for which number pairs were measured indicates that the variables are continuous. The smooth curve can be used to find number pairs that were not actually measured. For example, the line includes the number pair (85, 33). That is, a pendulum 85 centimeters long would swing 33 times in one minute.

One of the skills that you are expected to develop in this exercise is the ability to describe the relationships and trends shown in graphs. Figure 5, for example, indicates that as a pendulum is made shorter it swings more rapidly. The change in rate of swing for a given change in length is greater for short pendulums than for long ones. For example, shortening a 200-centimeter pendulum by 10 centimeters increases the rate only one swing per minute. But shortening a 60-centimeter pendulum by 10 centimeters increases the rate more than 7 swings per minute.

Before you begin constructing a point graph, some of the conventions used for constructing graphs in *Science—A Process*

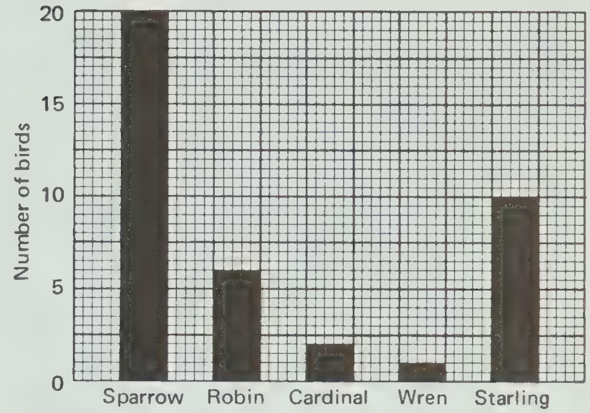

FIGURE 4

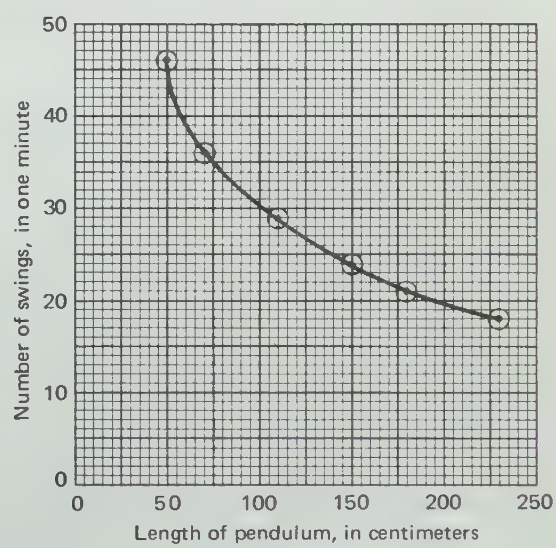

FIGURE 5

Approach are identified in the next paragraph. Study the graph (Figure 5) and try to make the correct choices in the statements which follow.

1. The (manipulated, responding) variable is graphed on the horizontal or x-axis.
2. The (responding, manipulated) variable is graphed on the vertical or y-axis.
3. Each axis (is, is not) labeled so as to describe what was manipulated and what was observed.
4. The intersection of the x-axis with the y-axis (is, is not) the zero- or starting-point of the *x* and *y* number lines.
5. The units of measurement of each pair of observations (are, are not) indicated along with the labels on the x-axis and the y-axis.
6. Numerals are placed along each axis at (regular, irregular) intervals as on a number line.
7. The numeral on the y-axis where a horizontal line crosses the y-axis determines the y-coordinate of any point on that horizontal line. (Yes, No)
8. The numeral on the x-axis where a vertical line crosses the x-axis determines the x-coordinate of any point on that vertical line. (Yes, No)
9. The graph (is, is not) a grid formed by horizontal and vertical lines, each line having an assigned value as shown by the numerals along the x-axis and the y-axis.
10. Numerals along each axis are placed (on, between) the vertical and horizontal lines of the grid.

Did you choose the first item of each pair of choices? In *Science—A Process Approach,* these ten statements form the conventions used in constructing graphs.

Now try your hand at constructing a graph of data you collect. To collect the data, you will need a paper cup with a flat bottom, a pin, a 100-milliliter graduated container, some water, and a stopwatch or a watch with a second hand. Make a pinhole in the bottom of the cup. Place your finger over the pinhole and fill the cup nearly full of water. Hold the cup so that the pinhole is directly over the 100-milliliter container, remove your finger, and immediately start timing. Rest the cup on the top of the container. Read and record the volume of water in the container every 20 seconds for three minutes. Then make a graph using the number pairs you have collected. Write a short statement describing the relationships of the variables and the trend shown by the graph. When you have finished, compare your graph and statement with the one in the *Comments on Activities* section. Question 4

COMMENTS ON ACTIVITIES

ACTIVITY 1 (QUESTION 1)

Here are some sample descriptions.

(1) It has two straight sides that meet at an angle of less than 90°. The ends of the straight sides are joined by a wavy line that has one sharp dip and two shallow dips in it.
(2) It has two straight sides that meet at an angle of less than 90°. One straight side is about twice as long as the other. The side opposite the short straight one is a smooth curve like a segment of a circle.
(3) It has two straight sides that are opposite each other and that appear to be parallel.
(4) It has two straight sides that meet at an angle of 90°. The shape looks something like a harp.
(5) It has two straight sides that meet at an angle of a little more than 90°. There is an indentation in the figure in the middle third of the longer straight side.

ACTIVITY 1 (QUESTION 2)

Before it was lighted, the yellow candle was about 5 centimeters long and 4 millimeters in diameter. A white wick about 1 millimeter in diameter extended about 3 millimeters from one end of the candle. The white wick turned black when the candle was lighted. As it burned, some liquid* formed just below the flame. Drops of the liquid ran down the outside of the candle at irregular intervals (several seconds) and formed smooth solid lumps on the side. Some of the liquid ran or dripped to the bottom and formed a pile of solid on one side of the candle. After burning for 5 minutes, the candle was 2 centimeters long.

When the candle was first lighted, the wick was about 3 millimeters long. After about one minute, the wick was about 1.5 centimeters long. As the candle became shorter, the wick did also, but continued to extend about 1.5 centimeters above the top of the candle. The wick remained white for about 3 millimeters above the top of the candle. The next 4 or 5 millimeters were black and the top 5 to 6 were bright red. The flame next to the wick and for about 3 millimeters above it was orange.

The base of the flame was pale blue and the upper half of the flame was bright yellowish white. The very top of the flame was orange. The flame was approximately ellipsoidal in shape, the top being somewhat pointed. The flame was 2 to

---

*This is a statement of an observation. To say that the wax below the flame melted would be an inference.

3 centimeters long and a little less than 1 centimeter in diameter at the widest point. The top of the flame moved constantly: first to one side and then another. When it moved far enough to one side, the tip of the wick was exposed for a second or less. When this happened, the tip of the wick turned white.

In about 10 minutes, the candle had burned down to the mass of yellow solid which was roughly circular, about 1 centimeter in diameter and 2 millimeters high. A pool of liquid formed in this yellow solid around the base of the flame. When this happened, the wick fell over, the flame went out, and the liquid solidified.

ACTIVITY 3 (QUESTION 3)

(a) 1.5 kilometers
(b) Jefferson Memorial
(c) Approximately 1.2 kilometers
(d) Approximately 4.3 kilometers
(e) About an hour

ACTIVITY 4 (QUESTION 4)

If your change did not contain one kind of coin, for example, half-dollars, you should have marked a place for that coin on your graph. The absence of a bar above it indicates that your change included no coins of that type.

The graph in Figure 6 is a plot of data similar to that which you collected when you measured the water flowing from a pinhole in a paper cup. Note that some of the observed number pairs do not lie on the curve. The curve was drawn as a *best fit* of the set of number pairs. Notice that of the number pairs that do not lie on the line, approximately half are above and half are below the line. In scientific work, it is generally assumed that deviation of a number pair from a smooth curve indicates an experimental error, such as failing to read the watch dial or the volume scale precisely.

The graph shows that the water flows through the hole fastest at the start and more slowly as time progresses.

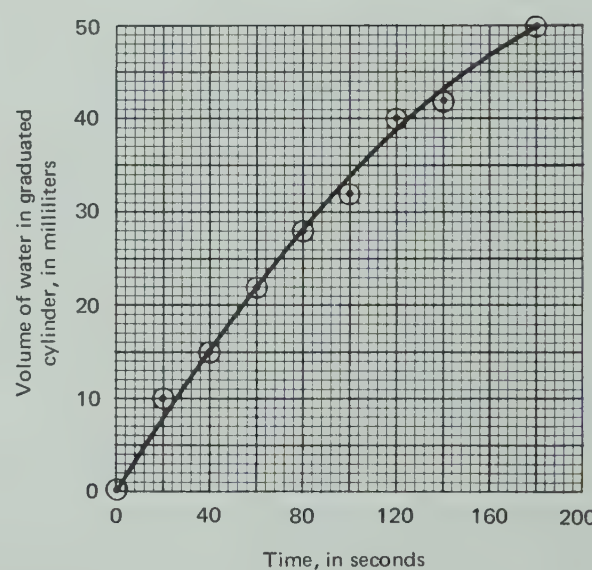

FIGURE 6

SELF-EVALUATION

1. Practice describing to a friend one object in a set of similar objects so that he can identify it. Use paper shapes, shells, nuts, large seeds, or any other set of objects.
2. Cut a piece of white paper towel to make a strip about 2 centimeters wide and 20 centimeters long. With black ink, make a mark about 3 millimeters wide across the strip, about 2 centimeters from one end. Turn the towel over and make the same mark on that side. Fountain pen

or felt pen ink is best; ball point ink is less satisfactory. Put water in a drinking glass to a depth of about 1 centimeter. Be careful not to wet the sides of the glass. Fold the top of the strip over the edge of the glass so the end of the strip is in the water, and the ink mark is about 1 centimeter above the water's surface. Observe the system closely for about five minutes. Make notes of any changes. Then make an observation every five or ten minutes for an hour.

3. Figure 7 shows an outline of a room. The room is 4 meters wide and 6 meters long. What is the scale of the map of the room? How wide is the door? There is a pole lamp in the room 1 meter from the north wall and 0.5 meter from the east wall. There is a sofa against the east wall. The sofa is 1 meter wide and 3 meters long. One end of the sofa is 2 meters from the north wall. There is a rectangular table in the room whose sides are parallel to the walls. The table is 1 meter wide and 2 meters long. One short side of the table is 1.5 meters from the south wall. One long side of the table is 0.2 meter from the west wall. Outline the sofa and table on the map and mark the position of the lamp with an X. What is the distance from the pole lamp to the northwest corner of the table?
4. Measure the length of a rubber band as different masses are suspended from it. Plot your measurements on a graph and write a description of relationships and trends in the graph. You can suspend the rubber band from a bent paper clip held to the edge of a table with a heavy book. Masses can be suspended from the rubber band in various ways. One way is to put them in a paper cup that is attached to the rubber band with a paper clip, as in Figure 8. The amount of mass you will need depends on the size of the rubber band. For a lightweight rubber band, you will probably need at least 500 grams and will want to add the masses in increments of 50 grams.

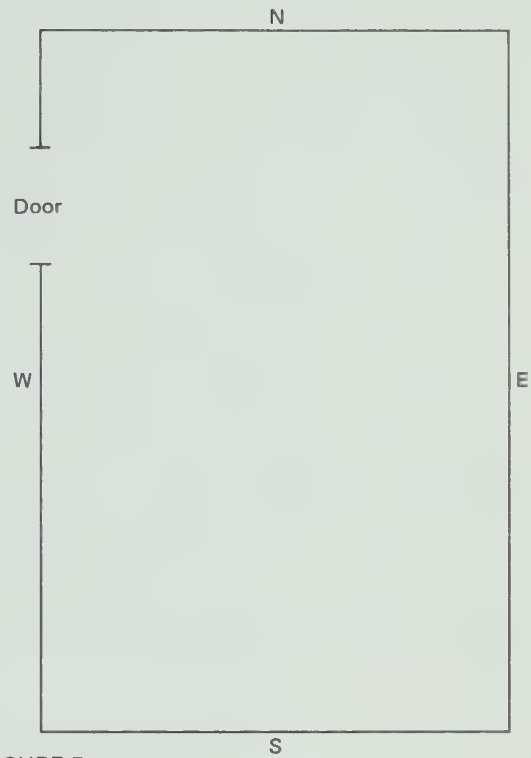

FIGURE 7

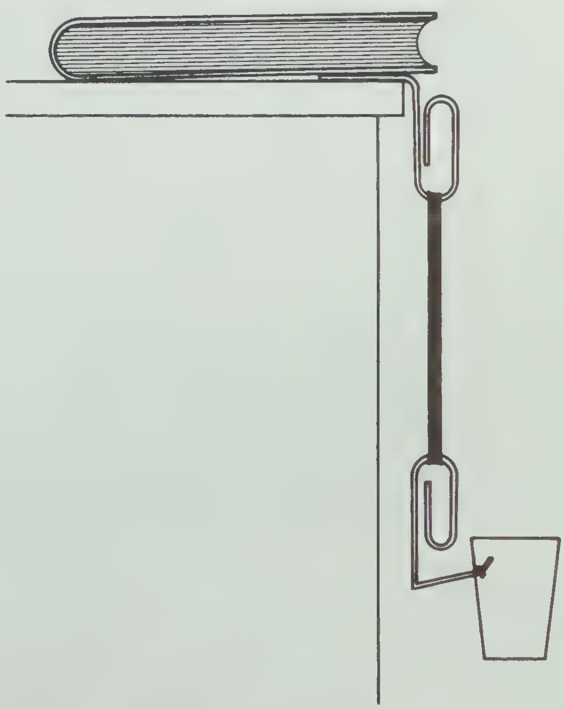

FIGURE 8

COMMENTS ON SELF-EVALUATION

1. Are you improving with practice?
2. Your description should include at least the following items.

   (a) How long it took the water to rise to different distances up the paper
   (b) How fast the ink mark spread
   (c) How the different colors separated (if that happened in your test)

3. Your map should look like Figure 9. The scale of the map is 1.5 centimeters to 1 meter. The door is 1 meter wide. The distance from the northwest corner of the table (A) to the pole lamp is 3.6 meters.
4. Figure 10 is a graph of some measurements made on the length of a rubber band when different masses were suspended from it. Your graph may be quite different, but should show a general increase in length with increase in mass. Verbally, you might describe the relationship shown in Figure 10 as follows.

The rubber band stretched most rapidly in the early stages of the investigation. The stretching diminished markedly at the end of the investigation. The amount of stretch per 100 grams of added weight can be determined by applying a series of straight lines to different sections of the graph. From 0 to 100 grams, the increase in length of the band was about 5 centimeters. From 150 to 250 grams, the amount of stretch doubled to about 10 centimeters. This is the steepest part of the curve. Between 300 and 500 grams the stretch was about 14 centimeters or 7 centimeters per 100 grams. Between 650 and 750 grams the stretch was only about 2 centimeters.

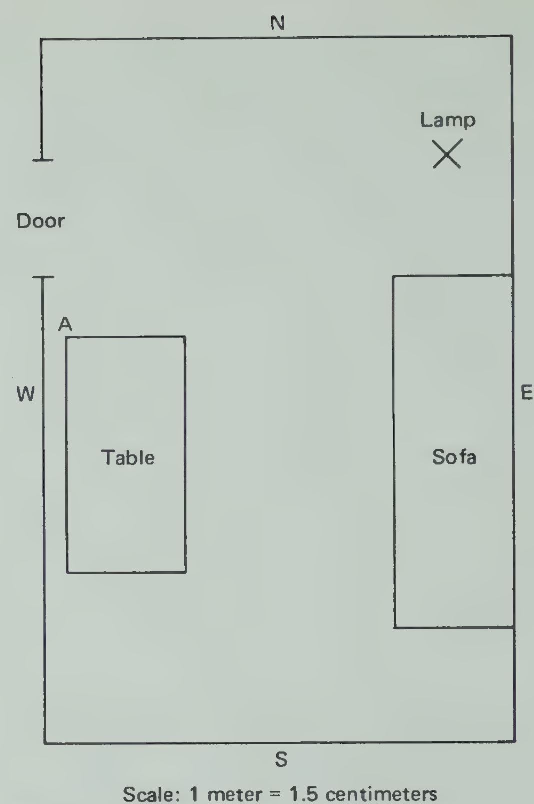

FIGURE 9

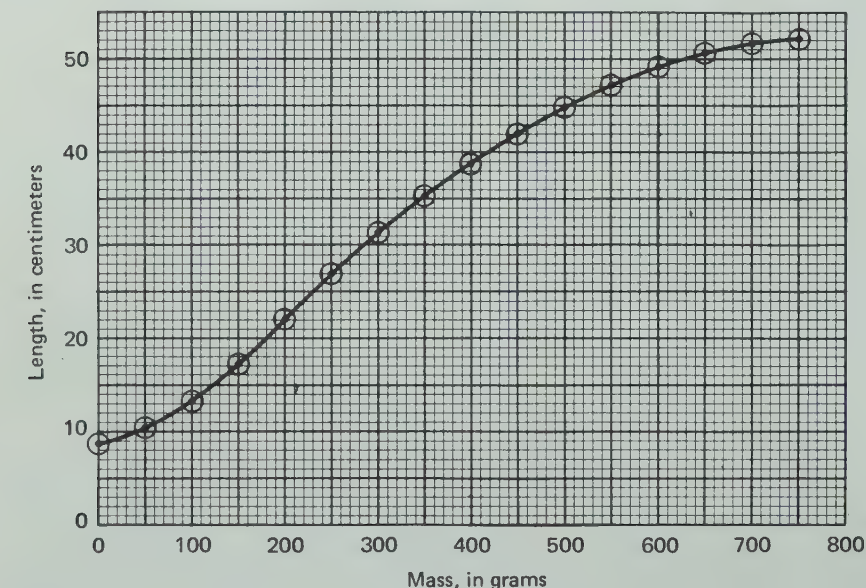

FIGURE 10

PREDICTING

OBJECTIVES

After you have studied this exercise you should be able to

1. *NAME* predictions by interpolating between observed events or by extrapolating beyond the range of observed events.
2. *CONSTRUCT* tests of a prediction.
3. *ORDER* a set of predictions in terms of your confidence in them.

RATIONALE

A prediction is a specific forecast of what a future observation will be. In *Science—A Process Approach,* predictions are based on observations, measurements, and inferences about relationships between observed variables. A prediction that is not based on observation is nothing more than a guess. Accurate predictions result from extensive and careful observation and from precise measurement.

When you make predictions, in the scientific sense of the word, you are usually expressing your confidence in the relationships you or others infer from observations. For example, a long history of observing natural phenomena in the physical universe has led us to infer that the universe is not capricious. We predict that the physical relationships we infer will continue to apply in the future.

For example, suppose you noted that the sun rose this morning at 5:35 A.M. You could then predict that the sun would rise at approximately 5:35 A.M. tomorrow morning. If you carefully timed the sunrise and sunset for each day in the year, you could predict with precision the time of sunrise and sunset for any day in the following year. You would be basing

your predictions on your own observations and measurements. Also, you would be basing your predictions on the historical record of times of sunrise and sunset.

For most predictions that arise in this program, a test is possible. As children test a prediction, they will be developing their ability to judge the reliability of other predictions. Furthermore, if a prediction is tested and found to be incorrect, the child has immediate feedback that should lead him to reexamine the basis for his prediction. Scientists act in much the same way if their predictions are found to be inaccurate.

The process of *Predicting* is closely interwoven with aspects of the *Communicating* process; both are concerned with graphing and with presenting data. Although children make predictions in many exercises, only five have predicting for the primary objective and carry the *Predicting* process label. In Part C, the children make predictions from very simple sets of data and from graphs. Later in the same Part, they make predictions on the basis of opinion surveys. In Parts D and E, the exercises deal with the motion of a bouncing ball, a suffocating candle, and various physical systems.

In this *Commentary* exercise, you will interpolate and extrapolate, using tables of data and graphs. This will be very useful in preparing to teach this program. As you acquire experience in judging the dependability of your predictions by interpolation and extrapolation, you may be thinking about relationships that are new to you. The experience will also emphasize the need for the children to develop two skills: the ability to construct reasonable predictions, and the ability to determine the dependability of their predictions.

VOCABULARY

extrapolate
interpolate

MATERIALS

Graph paper, 3 sheets
Large graduated cylinder or a wide-mouthed glass jar such as a one-gallon pickle jar, 1
Food-warming candle, 1
Blocks, about 2 centimeters thick, that will fit inside the cylinder or jar, 10
Stopwatch or watch with second hand, 1

Activity 1 — Making Predictions from a Table of Data

The table shown in Figure 1 presents data on the time of sunrise at 40°N latitude for certain days of the year. Given

Date	Time of Sunrise	Date	Time of Sunrise
January 1	7:22	July 1	4:34
January 15	7:20	July 15	4:44
February 1	7:09	August 1	4:58
February 15	6:54	September 1	5:27
March 1	6:34	October 1	5:56
April 1	5:44	November 1	6:29
May 1	5:01	December 1	7:02
June 1	4:33	December 15	7:14

FIGURE 1

such information, you can predict the time of sunrise on other days of the year for the same latitude. Study the table briefly. Predict when the sun will rise on April 15. Assume that the change in time for sunrise is the same from one day to the next through April.

Your calculation might look something like this:

Sunrise April 1	5:44	30 days	14 days
Sunrise April 15	?		
Sunrise May 1	5:01		
Difference	43 minutes		

$$\frac{14}{30} \times 43 = \frac{602}{30} = 20 \text{ (approximately)}$$

Thus, you would predict that the sun will rise at 5:24 on April 15. This procedure illustrates *interpolation* from the data in a table. That is, you are predicting a value *between* (or within) two given values. The data from the almanac agree with your prediction. The sun does rise at 5:24 on April 15. Now use this method to predict the sunrise on May 15. Is your prediction 4:48? The almanac shows 4:45 for May 15. Why does your predicted time of sunrise disagree with the time stated in the almanac? The next activity should help you answer this question.

Activity 2—Interpolating and Extrapolating from a Graph

Is there another way to make use of the data in Figure 1 to find the time of sunrise on April 15? Suppose you plot the data (date and time) on a graph. Construct such a graph. Plot the time scale on the vertical (y) axis, using a scale from 4:00 A.M. to 7:30 A.M., and the date scale on the horizontal (x) axis; plot the points (adding the sunrise times for April 15 and May 15 that are given in the text); then draw a smooth curve through the points. The graph should show that the difference in sunrise time from one day to the next changes considerably throughout the year. For example, the change is greater in March and October than it is in June and January. Question 1

Use your graph to predict the time of sunrise for August 15, September 15, October 15, and November 15. The correct times, taken from an almanac, are given at the end of this exercise. Don't look at the answers until you have made your predictions. Question 2

INTERPOLATING

Using your graph to make predictions—time and date—in between observed values is called *interpolation.* By interpo-

lating, you have made predictions of values that have not been included in the data on which a relationship has been established. If the observed values had not revealed a regular pattern, you would then have had no basis for an interpolation. Your prediction can be tested by observing the time of sunrise of the day for which you made the prediction (if you live at 40°N latitude, and if you have a clear horizon).

EXTRAPOLATING

Another method by which predictions can be made from data is *extrapolation.* Suppose you suspend a container on the end of a spring and add masses, one gram at a time, to the container. As the spring stretches, you measure the amount of stretch after adding each 1-gram mass. A graph of data collected in this way for one, two, three, and four 1-gram masses is shown in Figure 2.

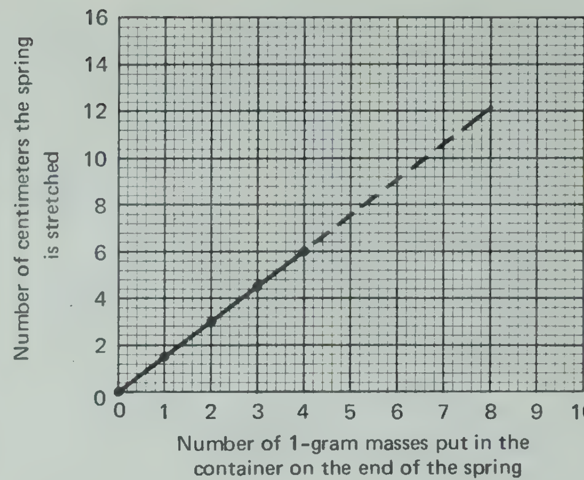

FIGURE 2

How can you use the graph to predict how much the spring would stretch if five 1-gram masses were added to the container? You can extend the line beyond (4, 6) and predict that *if the spring continues to stretch in a linear fashion,* it will stretch 7.5 centimeters. This process of extending a relationship beyond (outside) the range of observations is called *extrapolation.* By extrapolating, you have made a prediction that can be tested by making the appropriate observations.

What do you predict the length of the spring will be after eight 1-gram masses have been added? After twenty? Write your answers; then check the answers and comments at the end of this section. Do you feel as comfortable about your prediction of how much the spring will stretch with twenty 1-gram masses as you do about your prediction for five 1-gram masses? Why not? Probably you know that there is a point beyond which you cannot stretch a spring and have it recover. The farther away you go from the observed values, the less confident you are of your prediction. Extrapolating is usually considered a less secure basis for predicting than interpolating.

Question 3

Is it possible to extrapolate from the data in a table? Yes, but it is often more difficult and less reliable than from a graph. If the table reveals a pattern, as in Figure 3a, extrapolation from the pattern is quite reliable. Again, when data do not reveal a pattern, as for example in Figure 3b, extrapolation as well as interpolation would be nothing more than a guess.

X	Y
0	0
1	1
2	4
3	9
4	16
5	25

(a)

X	Y
0	0
1	3
2	4
3	3
4	0
5	$^{-}5$

(b)

FIGURE 3a-3b

Activity 3 — Confidence in Predictions

Predicting can be done with considerable confidence if all conditions except two variables are held constant. The time of sunrise is a good example of this. Only time of year (date)

and time of day vary significantly for our measurements. The speed of rotation of the earth and the direction of tilt of the earth's axis change so little over a limited period of time, or in such minor degree, that these changes can be ignored.

But in cases where variables other than the ones being manipulated do not remain strictly constant, the confidence you have in predicting may be somewhat shaky. In the exercise, *The Suffocating Candle, Predicting 4, Exercise m,* Part D, the burning time of a candle under jars of various sizes is measured. There are variables other than the sizes of the jars that might influence burning time. The shapes of the jars may be different, the jar may not be placed over the candle in the same way each time, the position of the candle inside the jar may vary and the height of the candle decreases as it burns. No doubt you can think of other variables in this situation. When you predict the burning time of a candle under jars of different volumes and different shapes, you should not be surprised if your prediction does not correspond exactly to the value you obtain as you test your prediction.

In order to illustrate this point, test your skill in predicting in a candle-jar system. Obtain a wide-mouthed glass jar, a food-warming candle, and 10 similar blocks. Light the candle, invert the jar over it, and measure the burning time with a stopwatch or a watch with a second hand. (See Figure 4.) Record your data. With a towel, wipe out the jar to renew the air inside it. Then, place the candle on one of the blocks, light it, invert the jar over it, and again record the burning time. Repeat the process with two, four, and seven blocks under the candle.

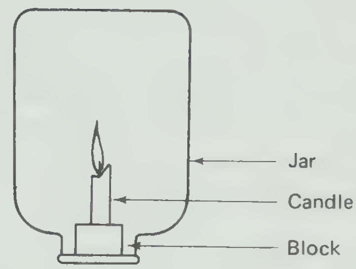

FIGURE 4

When you have all your data, make a graph. The number pairs are burning time (y-axis) and number of blocks (x-axis). Use the graph to predict the burning time with 3, 6, and 10 blocks under the candle. Test your predictions. How accurate were your predictions?

Question 4

You will find a graph useful when you wish to discern the nature of a relationship, that is, whether it is linear or whether the graph of the relationship is curved. Unless you have a great many points, you will have to exercise your judgment. For example, when you plotted the rising times of the sun, you probably thought it would be more reasonable to round the bottom part of the curve (as it changed slope from down to up) than to make a sharp change or angle, or a flat line. In this instance, the gradual curve was indicated by a decrease in the amount of change in a month's time from May 1 to June 1. Once the curve is established, whether or not it is linear, you will notice that it is possible to examine the graph at any coordinate on one axis and to read the corresponding coordinate on the other.

There are other kinds of predictions based on variables that are not held constant. For example, social scientists may predict that a candidate for public office will win or lose by a certain percentage. Such predictions are often based on public opinion surveys of sample populations. The surveys, and therefore the predictions, are subject to the vagaries of human behavior and may, of course, miss the mark by a wide margin. Predicting the weather is also difficult in many places in the world because the relationships among the variables are so complex and the number of variables is very great. In other places, where the weather is the same much of the time, accuracy of prediction may be as high as 95 to 99 percent.

Children in your classes should learn to make predictions based on observations recorded in a table or in a graph. They should learn to identify those predictions they can state with confidence and those they may have reason to question. They should endeavor to test their predictions as often as possible.

COMMENTS ON ACTIVITIES

ACTIVITY 2 (QUESTION 1)

See Figure 5.

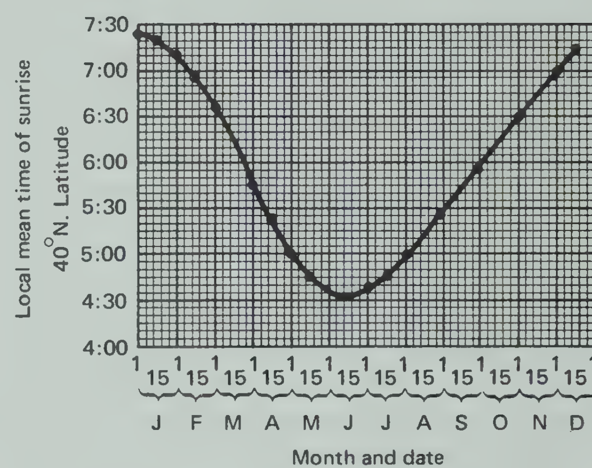

FIGURE 5

ACTIVITY 2 (QUESTION 2)

Interpolation

August 15	5:11
September 15	5:40
October 15	6:10
November 15	6:44

ACTIVITY 2 (QUESTION 3)

Extrapolation

8 grams, 12 centimeters
20 grams, 30 centimeters

In order to obtain these answers, it is assumed that the spring continues to stretch in a linear way. Of course, all springs finally reach the point where this is not so. Do you see the danger of extrapolating very far beyond your observations?

ACTIVITY 3 (QUESTION 4)

You probably found discrepancies between your predicted and observed values.

SELF-EVALUATION

1. Marbles, all of the same size, were dropped into a 100-milliliter graduated cylinder containing 20 milliliters of water. The water level was measured after 5, 10, and 15 marbles were dropped into the cylinder. The measurements were recorded and a bar graph was made of the data. Fifteen marbles raised the water level from 20 milliliters to 50 milliliters. How many marbles will raise the level to 80 milliliters? Did you answer this question by interpolating or extrapolating? Suppose you were asked, "If you added 500 marbles to the cylinder, what would happen?" How would you answer?

2. In Figure 6, observations were recorded about the extension of a spring when objects of equal mass were attached to the lower end of the spring.

   A. Construct a graph of the data in Figure 6.
   B. Predict the distance the spring is extended when 1, 3, 5, 7, and 100 objects are attached to the end of the spring.
   C. In predicting each of the distances in *B*, did you interpolate or extrapolate?
   D. Order your predictions in part *B* from most confidence to least confidence.
   E. Explain your order arrangement in part *D*.

Number of objects placed on end of spring	Distance in centimeters spring is extended
0	0
2	2
4	4
6	5

FIGURE 6

3. Consider the graph in Figure 7. It shows the change in weight of a baby as it grows older. The weight of the child was measured at birth, at 6 months of age, and at 12 months of age.

   A. By interpolating, predict the weight of the baby at the ages of 3 months and 9 months.
   B. State your degree of confidence, or lack of it, in each of the predictions made in *A*.
   C. By extrapolating, predict the weight of the baby at the age of 2 years, 3 years, and 5 years.
   D. State your degree of confidence, or lack of it, in each of the predictions made in *C*.

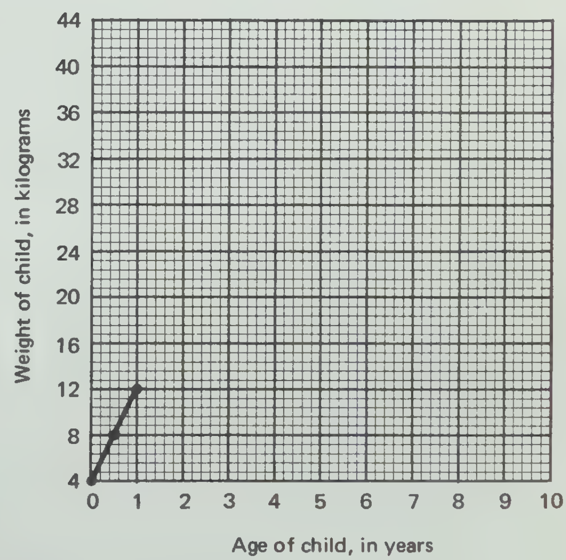

FIGURE 7

COMMENTS ON SELF-EVALUATION

1. The predicted number of marbles that would raise the water level from 20 milliliters to 80 milliliters may be found by extrapolating. The predicted number is 30 marbles.

The question about adding 500 marbles is not realistic, since the 100-milliliter container would not hold 500 marbles. However, if the container were large enough so that the marbles

could be added, the maximum level of the 20 milliliters of water would be reached long before 500 marbles were added. As soon as the level of the marbles and the level of 20 milliliters of water were the same, the addition of more marbles would no longer affect the water level. The extrapolation would not be valid beyond the point where the marbles were still covered by the water.

2.

A. See Figure 8.
B. The predictions are: 1 object, 1 centimeter; 3 objects, 3 centimeters; 5 objects, 4.5 centimeters; 7 objects, 5.4 to 5.5 centimeters; 100 objects, ? centimeters.
C. The first, second, and third predictions are made by interpolating; the last two predictions by extrapolating.
D. Order of confidence in predictions as follows.

First, second, third, fourth, fifth

E. You can have the most confidence in the first and second predictions because the graph is a straight line between 0 and 4 objects. Less confidence can be placed in the third and fourth predictions because the shape of the curve cannot be drawn accurately on the basis of only two observations (when 4 and 6 objects are attached to the spring). The fifth prediction cannot be made sensibly; no doubt fewer than 100 objects would stretch the spring out straight. It would probably break with considerably fewer than 100 objects attached to it. The correctness of a prediction can be determined only by making the observation and comparing it with the prediction.

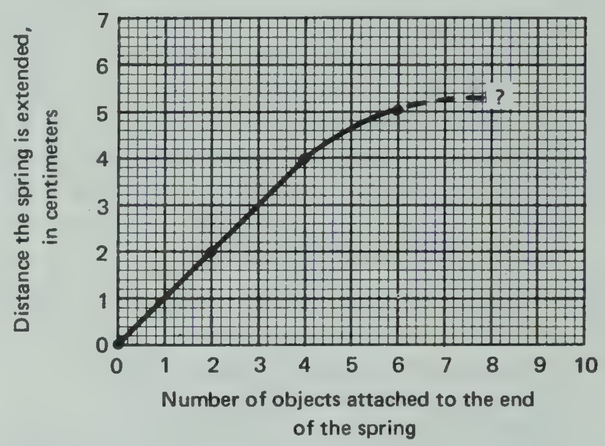

FIGURE 8

3.

A. The predicted weights at 3 and 9 months are 6 kilograms and 10 kilograms, respectively.
B. Both predictions are likely to be close to the weight actually observed. Of course, you cannot be certain because of a variety of factors.
C. The weight at 2 years of age is predicted to be 20 kilograms, at 3 years of age 28 kilograms, and at 5 years of age 44 kilograms.
D. There is increasing doubt in each of the predictions as the child ages. By carrying the extrapolation further, you can predict that the "child" at 50 years of age will weigh 404 kilograms. This result demonstrates the unreliability of extending extrapolation too far.

INFERRING

OBJECTIVES

After you have studied this exercise you should be able to

1. *CONSTRUCT* one or more inferences from a set of observations.
2. *IDENTIFY* observations that support an inference.
3. *DESCRIBE* and *DEMONSTRATE* additional observations needed to test alternative inferences.
4. *IDENTIFY* inferences that should be accepted, rejected or modified on the basis of additional observations.

RATIONALE

Nothing is more fundamental to clear and logical thought than the ability to distinguish between an observation and an inference. You can avoid many pitfalls in logical thinking if you make and use this distinction continually. An observation is an experience that is obtained through one of the senses. An inference is an explanation of an observation.

The thought process that is involved in constructing an inference may take place in a fraction of a second. This process is often strongly conditioned by past experiences. For example, it is raining and you see a bright flash outside the window. Almost immediately after the flash, you hear a loud crashing noise. In less than a second, you may begin to state your inference: *Lightning struck something not very far away.* This inference is an explanation of your observations: the flash of light and the loud noise. It is based on past experience with lightning and thunder and includes the knowledge

that the time interval between the flash and the sound is a measure of how far away the lightning struck. Would you have made a different inference if you had been a marine who had just returned from Vietnam?

It is important to remember that in many cases it is possible to make more than one inference to explain an observation or set of observations. How many times have you jumped to a conclusion to explain an observation, only to find out later that your inference was not supported by further observations?

The hot line between Washington and Moscow was constructed to decrease the chances that either the United States or Russia would jump to a conclusion about some international incident and act too hastily on the basis of that inference. Magicians carefully cultivate the art of inducing the audience to jump to a conclusion with one hasty inference to explain an observation. The audience sees the magician reach into a silk hat and pull out a rabbit, a balloon, and several other large objects. They are expected to infer that those objects were in the hat before the magician "pulled them out."

Scientists cultivate the ability to make at least one, and frequently more than one, carefully thought out inference to explain an observation or set of observations.

The activities stated in the objectives at the beginning of this exercise are central to all scientific investigations. Scientists make observations and construct several inferences about each. They then decide what new observations would help support the inferences. They make these new observations to see whether each of the inferences is an acceptable explanation of the new and the old observations.

Inferring is introduced in Part C, where the children make observations about packaged objects. They shake the boxes, smell them, and then infer what is inside the packages. Later on, in Part E, the children make observations using circuit boards. They make an inference about the pattern of the circuit board and test their inferences by making additional observations. Using the additional observations, some pupils find that their inferences have to be revised.

This exercise describes investigations of electric circuits, of water rising in tubes, and of structures inside a closed box. You will be asked to make inferences and to revise them on the basis of additional information.

VOCABULARY

inference	infer
circuit board	patterns
expand	

MATERIALS

Plastic vials, 24-milliliter, 2
Containers for water, about 400-milliliter, 2
Modeling clay or one-hole stoppers for vials
Stiff plastic tubes or soda straws, 2
30-centimeter ruler

Activity 1—Constructing One or More Inferences from a Set of Observations

Figure 1 shows a circuit board that has six metal contacts labeled *A, B, C, D, E,* and *F*. Some contacts are connected to each other by wires on the back of the board, but the wires cannot be seen. With a dry cell, lamp, and wires (shown in Figure 1), you can find out whether two contacts are connected by a hidden wire or wires. If the bulb lights when the wires are touched to two contacts, you can infer that they are connected by a wire, either directly or through one or more contacts. When this board was tested with the dry cell and bulb, the following results were obtained. (See Figure 2.)

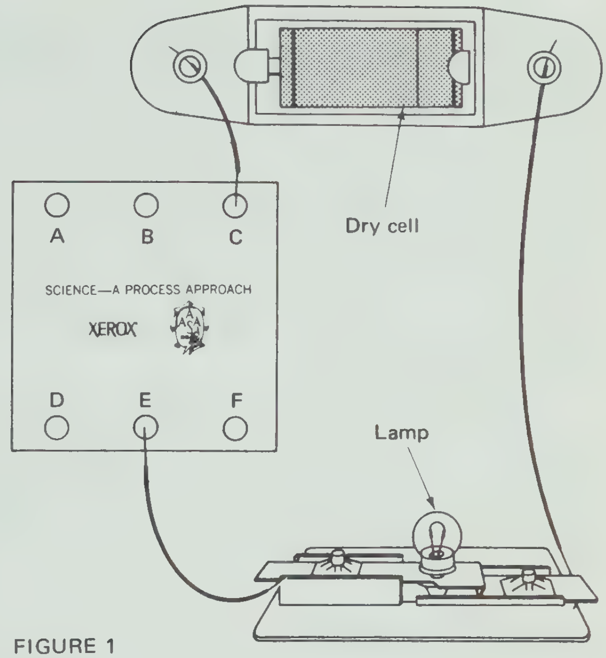

FIGURE 1

Contacts tested	AB	AC	AD	AE	AF	BC	BD	BE	BF	CD	CE	CF	DE	DF	EF
Response of bulb	+	-	+	-	+	-	+	-	+	-	-	-	-	+	-

FIGURE 2

The (+) indicates that the bulb lighted. From the results of these tests, you might assume that the board is wired as shown in Figure 3.

The pattern in Figure 3 could be the actual wiring pattern of the board. However, there are two things you should know about the board. First, in the actual wiring pattern, no more than two wires are connected to any contact. Notice, in Figure 3, that contacts *A, B, D,* and *F* each have three wires connected to them. Second, in the actual board, no wires cross. In Figure 3, the wires *AF* and *BD* cross each other.

With this additional information, draw several possible wiring diagrams for the circuit board. Remember, no wires cross, and not more than two wires originate from a contact. Eight inferred patterns for this board are shown in Figure 8 in the *Comments on Activities* section. Draw eight possible patterns, if you can, before looking at Figure 8. Can you decide, without further information, which of your inferred patterns is the actual wiring pattern?

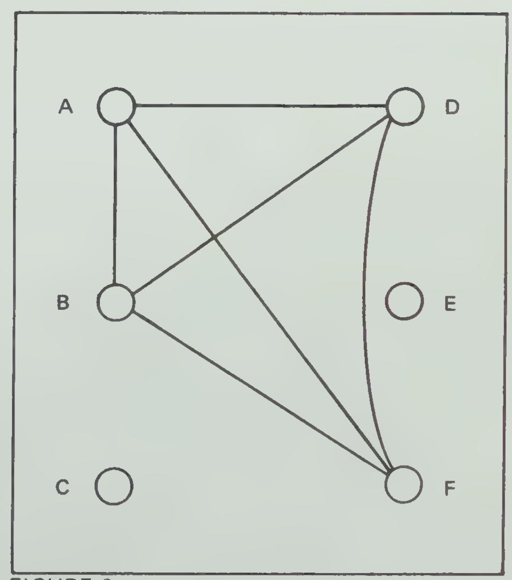

FIGURE 3

Question 1

Another six-contact circuit board was tested. The observations for five of the tests are shown in Figure 4. Draw one or more inferred patterns that could account for these five observations. After you have done this, try to infer whether or not the bulb would light when the following contacts are tested: *BC BD BE BF CD CE CF DE DF EF*. What is the basis for each of your inferences? Check your answers with those in the *Comments on Activities.*

Question 2

Contacts tested	AB	AC	AD	AE	AF
Response of bulb	+	-	+	+	-

FIGURE 4

Activity 2—Describing and Demonstrating Additional Observations

The following paragraphs describe some observations made on water rising in a tube attached to a plastic vial with a stopper or modeling clay. Two possible inferences are stated; each inference could explain the rise of the water in the tube. Your job will be to think of additional observations you might make to test the inferences.

The equipment used is shown in Figure 5. The two plastic vials are the same size (24 milliliters) and the tubes inserted in the vials are the same size bore. The stoppers are airtight and the tubes are open at the top. Vial *A* contains 16 milliliters of water and 8 milliliters of air, and Vial *B* contains 8 milliliters of water and 16 milliliters of air. The top of the water column in each tube is marked, and both vials are placed in a beaker of hot water that has a temperature of 70°C. Both vials are submerged up to the bottoms of the stoppers. In 30 seconds the water in Vial *B* rose 6 centimeters in the tube. In Vial *A*, the water rose 3 centimeters in 30 seconds.

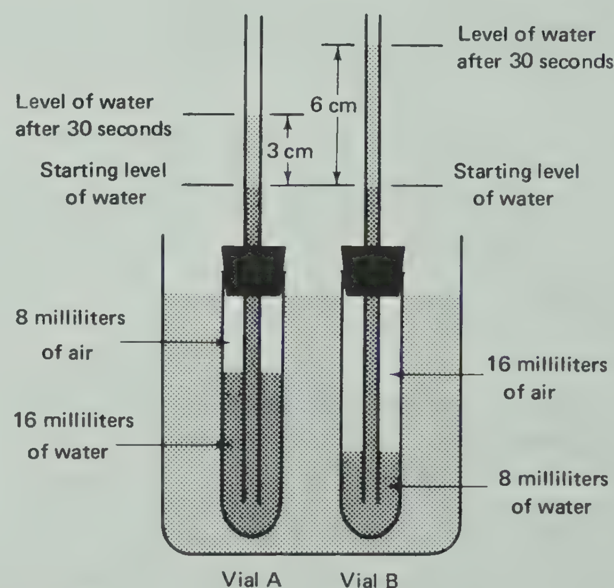

FIGURE 5

A student who made these observations made this statement: Water expands when it is heated. The time it takes to heat water depends on how much is being heated. The larger the volume of water the longer it takes to heat it. He then made this inference: *The water rose only half as far in Vial A, containing 16 milliliters of water, as in Vial B, containing 8 milliliters of water, because there was twice as much water in A as in B.*

Another student who made the same observations made this statement: Air expands when it is heated. He then made this inference: *It was the expanding air that pushed the water up the tube. There were 16 milliliters of air in Vial B and only 8 milliliters in Vial A. Therefore, the water rose twice as fast in the tube inside the vial containing 16 milliliters of air as in the one inside the vial containing 8 milliliters of air.*

Question 3

What additional observations would you make to determine which inference is the better explanation of the observation? List the steps you would go through in making new observations. Which observations would support and which would not support each of the inferences? If you have some vials,

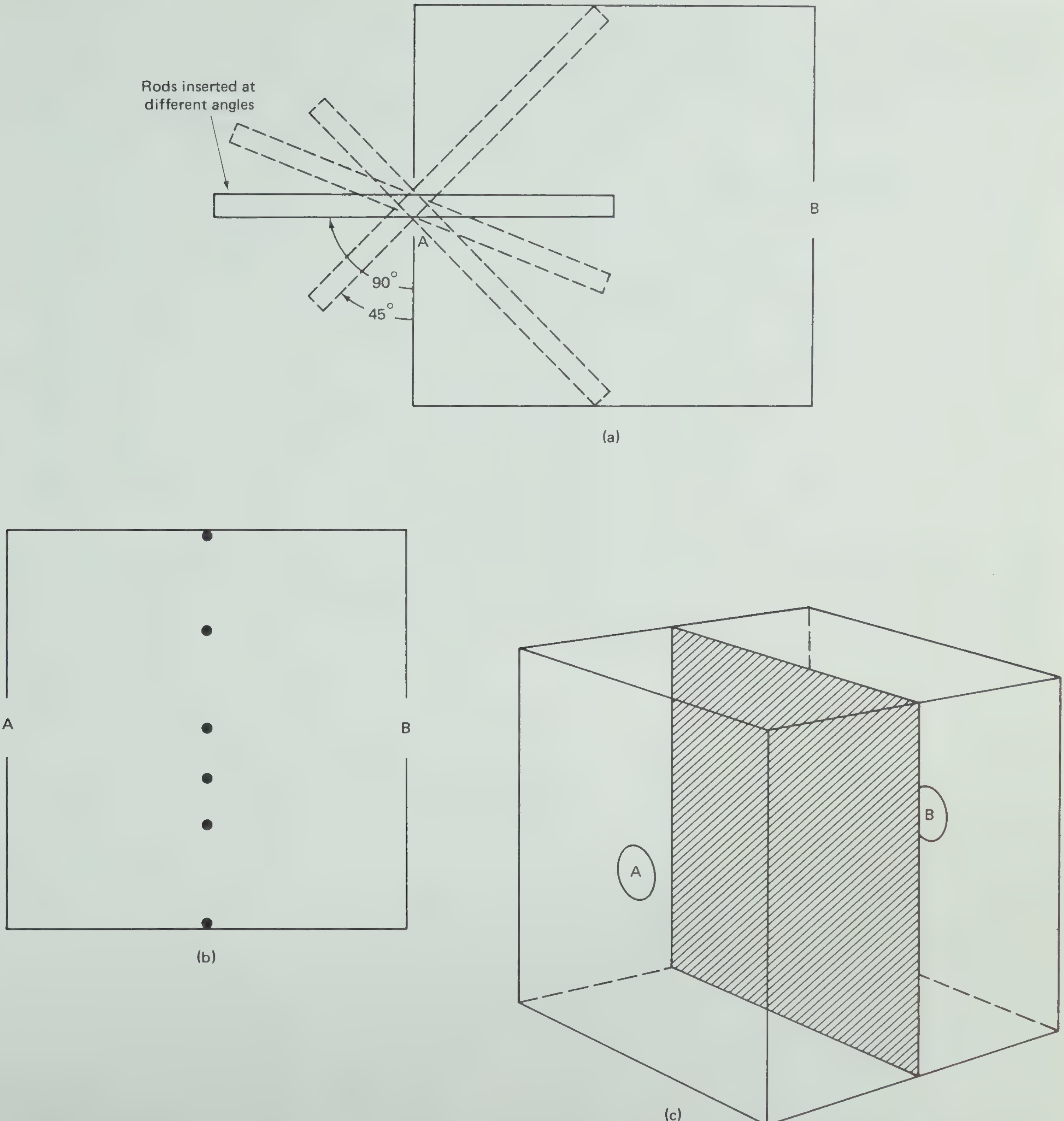

FIGURE 6

stoppers (or modeling clay), and tubes (or soda straws), you might follow the procedures you suggest. After you have planned your procedure (and made your observations, if you have the equipment), read the two suggestions made in the *Comments on Activities.*

Activity 3—Identifying Inferences That Should Be Modified on the Basis of Additional Observations

Suppose someone gave you a closed box and asked you to make observations about it. He also asked you to infer the shape of something inside the box. Each edge of the box is 7 centimeters long. There is a hole large enough to stick a thin rod through in the center of two of the opposite sides. The interior is completely dark when you look through either hole, so you infer there is some sort of partition in the box.

Let's assume you start your observations by sticking a rod into the box through hole *A*. (See Figure 6a.) Further assume that you measure how far into the box the rod goes. You try this at different angles and mark points on a sketch of the box, as in Figure 6b. From these observations, you infer that there is a partition in the box, as shown in Figure 6c.

Next, you make some measurements through hole *B*. The angles at which the rod was inserted and the distance it went into the box are shown in Figure 7. Do these new observations support your inference about the structure inside the box? If not, can you modify your inference to account for the new observations? Question 4

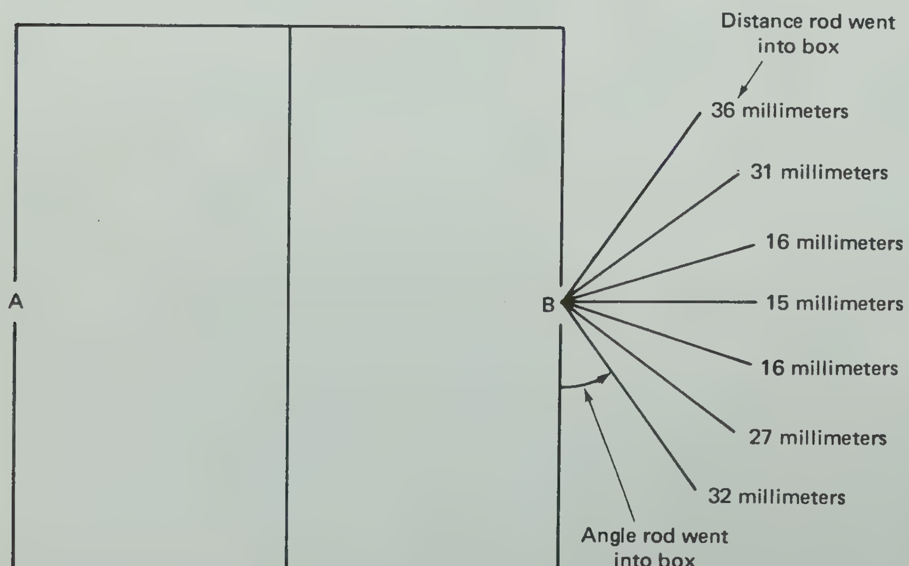

FIGURE 7

COMMENTS ON ACTIVITIES

ACTIVITY 1 (QUESTION 1)

Without more information than was given in the activity, you cannot decide which of your inferred patterns corresponded to the actual wiring pattern of the board. Eight possible patterns for this circuit board are shown in Figure 8.

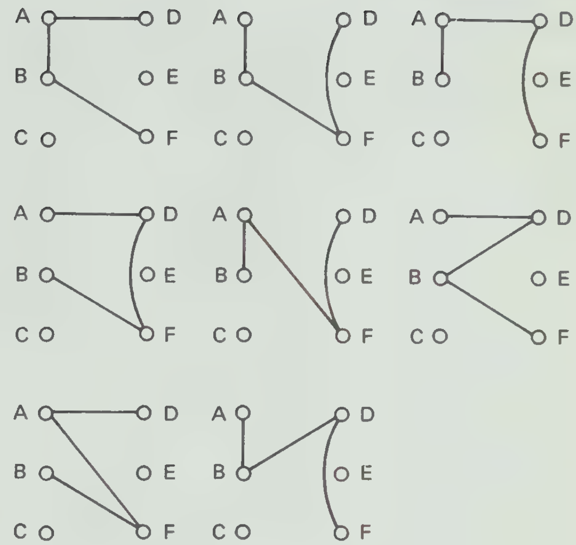

FIGURE 8

ACTIVITY 1 (QUESTION 2)

You may have made the following inferences for the tests on the remaining pairs of contacts.

The bulb will light when these contacts are tested: BD, BE, and *DE.*

This inference is based on the observations that the bulb lighted when *AB, AD,* and *AE* were tested. *A, B, D,* and *E* must be connected and, again, at least eight patterns of connections can be inferred, if no wires are crossed and no more than two connections are allowed at any contact. Figure 9 illustrates eight possible patterns. *The bulb will not light when these contacts are tested: BC, BF, CD, CE, CF, DF,* and *EF.* This inference is based on the observation that the bulb did not light when *AC* and *AF* were tested. *C* and *F* must not be connected in any way to *A, B, D,* and *E,* which are interconnected as described above. You have no information to tell whether or not *C* and *F* are connected.

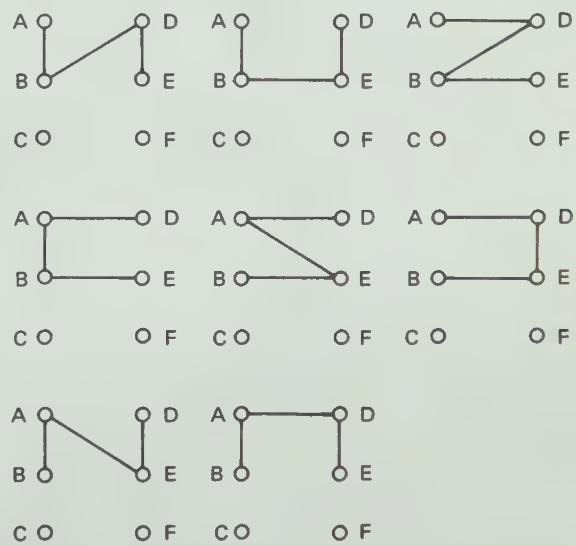

FIGURE 9

ACTIVITY 2 (QUESTION 3)

There are many additional observations that you may think of. Here are two examples:

1. When the vials have returned to room temperature, immerse them again in hot water in the beaker, but only as deep as the top surface of the water in each vial. If the water columns in the tubes rise about as far in 30 seconds as before, Inference 1 is supported and Inference 2 is not.

2. Use three or more vials with different volumes (for example 25, 50 and 75 milliliters). Put the same volume of water in each vial. If the water rises fastest in the tube attached to the largest vial, and slowest in the tube attached to the smallest vial, Inference 2 is supported and Inference 1 is not.

ACTIVITY 3 (QUESTION 4)

A number of possible shapes inside the box would account for the observations made through holes *A* and *B.* Two possible structures are shown in Figure 10.

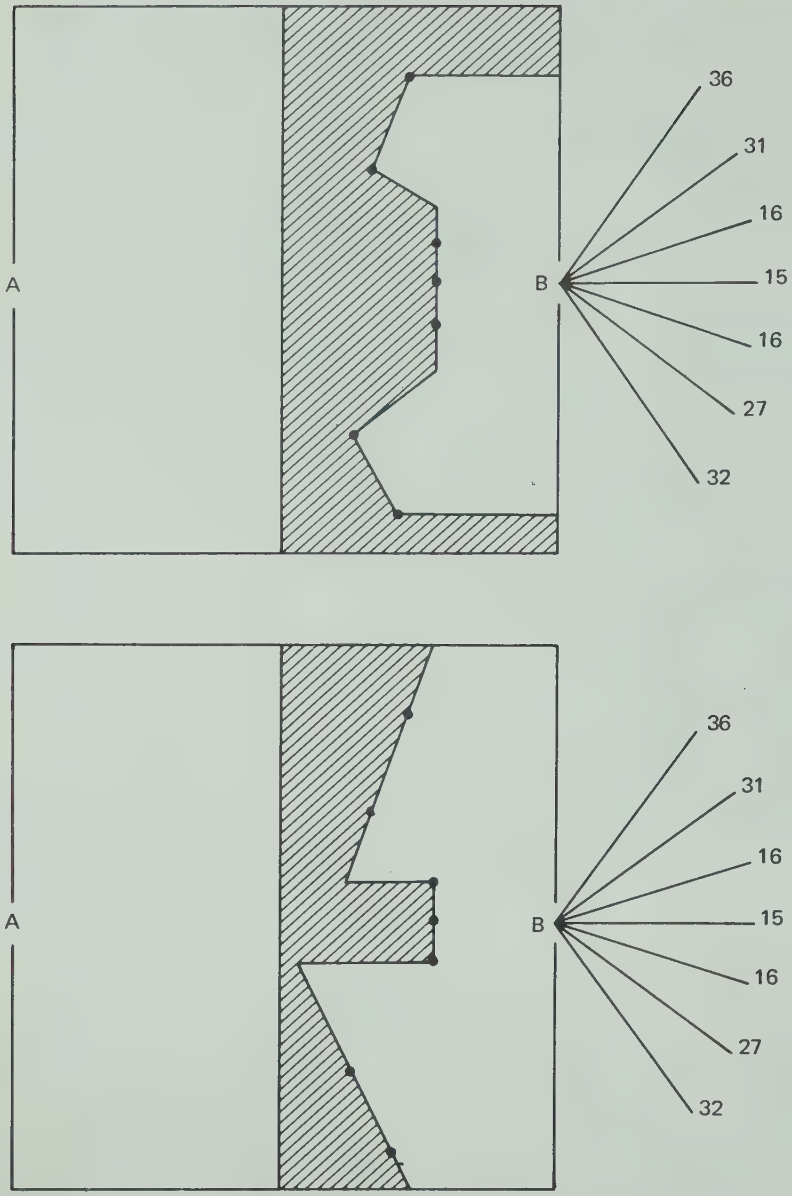

FIGURE 10

SELF-EVALUATION

1. Hold a red object, a red pencil for example, about 20 centimeters from your face and look at it steadily for about 30 seconds. Then close your eyes and put your hands over them to exclude any light. Do you observe anything with your eyes closed? State your observations. Next, repeat the activity using a green object. State your observations. What inference (or inferences) can you make to explain your observations?

2. Now use a yellow object and repeat the test you made above. Do your observations support the inference you made in Question 1? If not, is there another test you could make? If so, make the test and state whether you should accept, reject or modify your inference on the basis of your new observations.

COMMENTS ON SELF-EVALUATION

1. You probably saw a green after-image of the red pencil and a red after-image of the green pencil. A simple inference about these observations might be: The color of the after-image of an object is the complementary color of the color of the object itself. The color wheel and the concept of complementary colors are discussed in *The Color Wheel—An Order Arrangement, Classifying 8, Exercise q,* Part C.

   Another inference that does not require this knowledge might be: The color of the after-image of a colored object is different from the color of the object itself. A second object, which is the same color as the after-image, gives an after-image that is the same color as the first object.
2. You probably saw a blue or purple after-image when you gazed at the yellow object. This observation supports the first of the above inferences. You might also try observing a blue object. If this gives a yellow or orange after-image, it supports both inferences.

PART 3: THE INTEGRATED PROCESSES

CONTROLLING VARIABLES

OBJECTIVES

After you have studied this exercise you should be able to

1. *IDENTIFY* variables which may influence the behavior or the properties of a physical or biological system.
2. *IDENTIFY* variables which are manipulated, responding, or held constant in an investigation or an experiment.
3. *DISTINGUISH* between conditions which hold a given variable constant and conditions which do not hold a variable constant.
4. *CONSTRUCT* a test to determine the effects of one or more variables on a responding variable.
5. *IDENTIFY* and *NAME* variables which were not held constant in the description of an investigation, although they varied in the same way in all treatments or were randomized.

RATIONALE

You have probably heard a housewife remark, following a baking fiasco, "I can't understand why the cake didn't turn out. I did everything exactly the same as I always have." It is reasonable to suspect that something was different, even though the cook did not know it. Perhaps it was an unnoticed change in the ingredients, the length of time the eggs were beaten, the temperature of the butter, the age of the eggs, or any one of a great number of factors. Each of these factors is a *variable,* which may have influenced the quality of the cake. In this exercise, you will be thinking about variables and how they may influence one another.

The process of *Controlling Variables* is pervasive in scientific inquiry. The most definitive results of an investigation are obtained when the variables can be identified and carefully controlled. You will have the best possible evidence from your investigations if you follow these steps: Change (manipulate) one variable in a systematic way, and watch for and measure corresponding changes in another (the responding) variable; hold constant (keep the same) all the other variables you can think of while you are manipulating one variable and observing the response of another. It is not always possible to attain this ideal, but scientists always strive for it.

There are twelve exercises in Parts E, F, and G which focus on developing the children's skill in identifying and working with variables; the children should be thoroughly familiar with all elements of the process by the time they approach the *Experimenting* process in Part G. The twelve *Controlling Variables* exercises range over a wide variety of content, including investigations of rolling cylinders; the upward movement of liquids in materials such as blotters, fabrics, and sand; growth of mold; loss of moisture in potatoes; memorizing, relearning, and human reaction time; chemical reactions; growth of plants; and growth and behavior of animals. The pupil's ability to plan and carry out his experiments successfully in Part G will depend very heavily on his competence in *Controlling Variables.*

Use of the words *experiment* and *experimenting* are reserved for Part G, since the process of *Experimenting* becomes the culminating process of the program, a process that clearly depends upon competence in all of the other processes. Thus, in this *Commentary* exercise, the word *investigation* is used instead of experiment.

VOCABULARY

variable	responding variable
controlled variable	variable held constant (never *constant variable*)
manipulated variable	

MATERIALS

No materials are needed, unless you wish to try out some of the investigations discussed.

Activity 1—Variables in Observing a Picture

Observe Figure 1, which is constructed with only three sizes of black dots. Do you recognize the object in the picture? Now, prop the page in a vertical position, and as you look at the picture, walk slowly away from it. Keep walking until

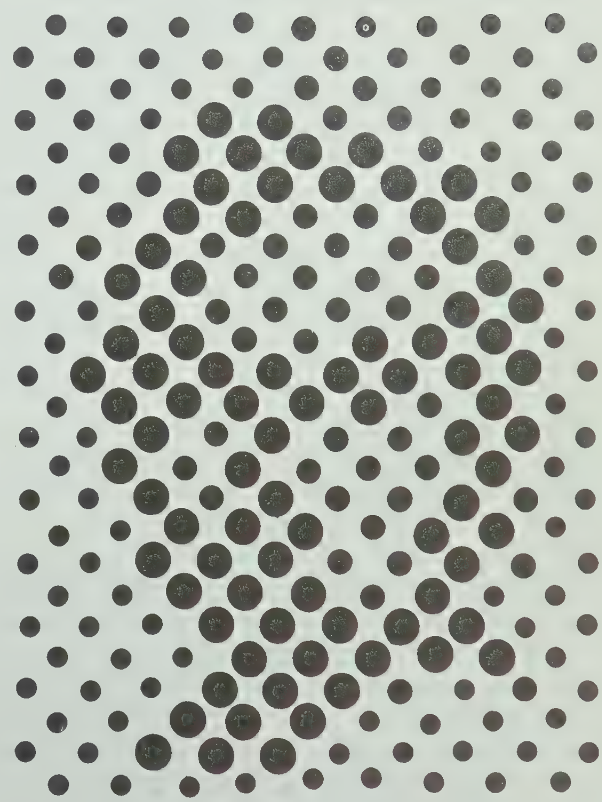

FIGURE 1

you can name the object in the picture, and then continue reading.

As you walked away from the picture, you eventually were so far away that the dots appeared to merge into one another and the object in the picture became apparent. At what distance, in metric units, did this occur? Try it again if you didn't notice the distance. The distance at which you first recognized the object can be called a variable—something that was part of the event or situation. Other variables in this example include the color of the wall in the room where you are looking at the picture, the amount of light shining directly on the book, and the quality of your vision.

Make a list of the variables that you infer may have an influence on the distance at which you are first able to recognize the object in the picture of Figure 1. Some of these variables are listed in the *Comments on Activities,* but be sure to make your list before turning to that section. Question 1

Suppose you infer that the distance at which the object is just recognizable (resolved) depends on whether you start close to the picture and walk away from it or begin at a long distance away and approach the picture. In this inference, there are two variables—the direction of your movement in relation to the picture and the distance at which the picture is recognized. It should be quite easy to devise an investigation of the relationships between these two variables. Think about how you could investigate this situation before reading the next paragraph. Then check your plan with the one proposed in the following paragraph, and try your test or the one described.

You could first begin at a distance beyond which the picture is recognized and then move toward it. Measure the distance at which you think you are able to recognize the face. Then begin at a position close to the picture and move away from it. Measure the distance at which you think you are just able to recognize the face in the picture. If the illumination, color, observer, and so on, were unchanged, you should be able to make some statement about the influence of the variable *direction of approach* on the variable *distance at which the face in the picture is recognized.*

In the test described (or the one you planned yourself), what variables are held constant? That is, were any variables not allowed to change? Which ones? Question 2

Which variables are allowed to change? (The direction of your movement in relation to the picture, and the distance from the picture at which you identify the object.) Which of these variables did you manipulate? In the test described above, you walked toward the picture and then away from it. In other words, you manipulated the *direction* of your

motion. The *direction* is called the *manipulated variable.* The variable *distance* is called the *responding variable.*

So far, three kinds of variables have been identified and named: the manipulated variable, the responding variable, and the variables held constant. In the test just described, all of these variables were controlled. How can this be? Certainly the variables which were held constant were controlled. The manipulated variable was controlled at your will. The responding variable was controlled by the manipulated variable. So, all variables were *controlled* in this test. Usually, most variables in a test or investigation are held constant, one is manipulated, and another responds. Sometimes, more than one variable is manipulated, either by design or because it cannot be helped.

In manipulating the variable in this example (direction of movement in relation to the picture), only two possible values of this variable were considered. What were they? What other values might have been assigned to this variable?

Question 3
Question 4

You have been conducting an investigation in which you manipulated the variable, *direction of movement in relation to the picture.* Look at the list of variables in this situation (either your list or the one given in the *Comments on Activities*). What other variable or variables might be tested in order to determine the distance from the picture at which the object could be recognized? Could the amount of light in the room be manipulated as a variable in a different investigation? How about the height of the picture above the floor? The answers to these questions are *yes.* The questions are asked to emphasize that several variables might have been manipulated. This is not to suggest that more than one variable be manipulated at a time. In elementary classrooms, you should try to restrict investigations to those in which only one variable is manipulated at a time.

Before leaving this *Activity,* you may wish to read *Resolving Power of the Eye, Experimenting 3, Exercise h,* Part G as a matter of interest in the topic itself.

Activity 2—Planning Several Tests of an Inference or Hypothesis

In *Rolling Cylinders, Controlling Variables 1, Exercise b,* Part E, the children are given a number of cylinders and an inclined plane on which to roll them. They are asked to identify variables that influence the time required for the cylinders to roll down the inclined plane. After rolling quite a number of the cylinders on the inclined plane, they list the the variables. In their investigations, they do not use a timepiece to record the time. Rather, they roll two cylinders at a

time, under the same conditions, and compare rolling times by pairs.

If you teach Part E and have the materials available, or if you can obtain them from another teacher, try rolling several pairs of cylinders down the incline before you proceed further with this discussion.

Suppose you are given a set of cylinders made of several materials, of different diameters and lengths, of different masses, and some hollow and some solid. A list of variables that might influence rolling time for these cylinders includes:

1. Height from which cylinder is rolled
2. Material of which cylinder is made
3. Mass of cylinder
4. Diameter of cylinder
5. Length of cylinder
6. Structure of cylinder (hollow or solid)

Among these variables, there are many combinations that might have an influence on rolling time. For example, would a long, heavy, solid steel cylinder roll down faster than a short, solid, plastic cylinder?

Suppose you decide that the mass of the cylinder might have an influence on rolling time, and want to conduct an investigation to find out whether this is the case. In your plan for the investigation, what is the manipulated variable? (Mass.) What is the responding variable? (Rolling time.) What variables from the above list would you hold constant, and how would you hold them constant? Question 5

Describe two cylinders you could compare for rolling time. Suppose you choose cylinders *A* and *B* as follows:

A: mass x; length, 10 centimeters; diameter, 20 millimeters; made of steel; solid

B: mass y; length, 10 centimeters; diameter, 20 millimeters; made of plastic; solid

Mass x is greater than mass y. You roll *A* and *B* from the same height. Do you control all the variables above? (Yes.) Do you manipulate more than one variable? (Actually, yes, since both mass and material are manipulated.) Suppose you find that the two cylinders reach the bottom of the plane at the same time. What do you infer? (The differences in mass and material in *A* and *B* do not influence rolling time.)

Suppose you roll the same pair down the incline again. They reach the bottom at the same time. You try two other solid cylinders, both longer this time, but of the same diameter, one made of plastic and the other of steel. Again, you find that they roll down the incline in the same time, if they are started from the same height at the same time. You try

two shorter cylinders, and then pairs of several lengths, first of larger and then of smaller diameters. The pairs stay together as they roll down the incline. You become more certain that mass (and material) have no influence on rolling time.

Next, you try another pair of cylinders whose mass you can vary. Both are made of steel, but one is longer than the other. Once again, you manipulate two variables, but this time they are *mass* and *length*. The cylinders are otherwise identical: both are solid, both have the same diameter, and you start them from the same height on the incline at the same time. Again, the two cylinders reach the bottom of the incline at the same time. Mass and length do not seem to influence rolling time, you infer.

Then you decide to vary mass in another way. You roll a pair of steel cylinders: both are the same length and diameter, but one is hollow and the other is solid. You start them at the same time from the same height on the incline. This time the solid cylinder is clearly the winner. Now what do you do? What do you infer? Question 6

If you can actually test the cylinders, you will find that the most decisive factor in difference of rolling time is whether the cylinder is hollow or solid. This may surprise you. The explanation of this phenomenon has to do with the distribution of mass with respect to the axis of rotation.

The rolling cylinder example offers other possibilities for manipulating one variable and controlling others. Design as many other investigations of factors that influence rolling times of cylinders as you can. Variables that may affect rolling time are fairly easy to identify, but there are certain complications. The variables identified may not be independent of one another. For example, the mass depends upon volume and material and the volume depends upon length and diameter. Thus, particular care must be used in constructing inferences following trial tests.

Activity 3—Other Considerations in Holding Variables Constant

In an ideal investigation, you should control all variables that you infer might influence a system, behavior, or event. But few investigations are ideal, as you have already seen. It is often difficult or impossible to control all variables.

In *Controlling Variables* exercises of Parts E, F, and G, pupils identify variables that might influence the responding variable, but that the pupils cannot hold constant in the usual sense of the term. You will consider two of these situations in this activity.

A. An investigation was made of nutrients that promote plant growth. A group of pupils was given four young tomato plants as nearly alike as possible. Each plant was placed in a 15-centimeter pot containing potting soil. The plants were placed on a window sill at the south side of the classroom, and watered the same amount each day and at the same time. In Pot *A,* the group added nutrient *A* to the soil; in Pot *B,* nutrient *B*; in Pot *C,* nutrient *C*; and they put no nutrient in Pot *D*. List the variables that you think influenced the growth of the plant. Which variable was the manipulated variable? Which variables were held constant? Which variables were not held constant but changed in the same way for all treatments? Are these variables controlled variables? Question 7 Question 8 Question 9 Question 10

B. In an investigation of learning, a class of children was divided into two groups, *A* and *B*. The teacher typed the children's names on cards. Allen and Betty drew names alternately. The names that Allen drew were placed in Group *A,* and those that Betty drew were placed in Group *B.* Group *A* was given a programmed set of materials from which they were to learn the names of twenty trees from pictures of the trees, their leaves, and fruits. Group *B* was given the same pictures and was told to study them in any way it chose. Each group was allowed to work the first twenty minutes of each school day for three days. The teacher did not answer any questions of either group during the study period.

For this investigation, list all variables that might influence the number of tree names learned. Name the manipulated variable, the responding variable, and the variables held constant. Question 11

Was the variable, the *constituency of the groups,* held constant? (No. The identical children could not be in both groups.)

How did the teacher try to control (although not hold constant) this variable? Question 12

COMMENTS ON ACTIVITIES

ACTIVITY 1 (QUESTION 1)

1. The distance of the observer from the picture
2. The observer (eyesight, sensitivity of retina, color-blindness)
3. The light in the room
4. The light directly illuminating the picture
5. The color of the light illuminating the picture

6. The direction of approach of the observer to the picture
7. The amount of practice the observer has had
8. Whether or not the observer has recognized the object in the picture prior to determining the distance

ACTIVITY 1 (QUESTION 2)

Variables that should be held constant include *illumination on picture, speed of walking, person being tested, position of picture.*

ACTIVITY 1 (QUESTIONS 3 AND 4)

The two values are walking directly toward the picture and walking directly away from it. You might have walked toward or away from the picture at an angle different from 90°.

ACTIVITY 2 (QUESTION 5)

Variables 1, 4, 5, and 6 should be held constant, and you might like to hold 2 constant as well. But, can you do this while holding 4, 5, and 6 constant?

ACTIVITY 2 (QUESTION 6)

You infer that it is the characteristic of being solid or hollow that influences rolling time. Next, you try to find a solid cylinder whose mass is about the same as the mass of the hollow steel cylinder, and you roll these. Then, you try different pairs of solid and hollow cylinders to test your inference in as many ways as possible.

ACTIVITY 3 (QUESTION 7)

Some of the variables are:

1. Age of plants
2. Height and mass of plants
3. Color of plants
4. Potting soil
5. Size of pots
6. Frequency and amount of watering
7. Light in room
8. Temperature in room
9. Nutrient in soil

ACTIVITY 3 (QUESTION 8)

9

ACTIVITY 3 (QUESTION 9)

1, 2, 3, 4, 5, 6

ACTIVITY 3 (QUESTION 10)

7 and 8. Yes, these variables are considered to be controlled

for the purposes of this investigation, since they changed in the same way for all specimens. They were not held constant, since part of the day it was dark, and undoubtedly the temperature was lower at night and higher in the day.

ACTIVITY 3 (QUESTION 11)

Manipulated variable—method of study; responding variable—number of tree names learned. Variables held constant included: teacher, classroom, pictures, study schedule, amount of time for study, and number of questions answered by teacher.

ACTIVITY 3 (QUESTION 12)

The teacher tried to compensate for differences in individuals in Groups *A* and *B* by choosing the members of the two groups at *random*. In statistics, this would be called *randomization*. This method does not guarantee that the groups were equal in ability, interest, perseverance, or any other possible variation of qualities among individuals. Under the circumstances, it is probably the best way to "control" the variable of individual differences. The teacher might have used a matching process (equal numbers of boys and girls in each group, equal numbers of *A* pupils, equal numbers of left-handed children, and so on), but this would be more difficult and the criteria questionable.

SELF-EVALUATION

1. It is reported that Galileo, while attending Mass in the Cathedral of Pisa, noticed a swinging chandelier and became interested in the time it took for the chandelier to move from one end of its swing to the other and back to its original position. He discovered a fundamental law about pendulums as a result of his subsequent investigations. We will not mention the law here, since it might limit your consideration of the following questions, but you may want to look it up when you have finished this exercise.

In answering the following questions, consider a pendulum to be an object (the pendulum bob) suspended by a string (or other means of support). The time for a complete swing of a pendulum is called the *period* of the pendulum.

   a. Identify the variables that you think might affect the period of a pendulum
   b. Is the period a variable?

c. How would you control each variable in order to determine experimentally the effect one of these variables has on the period of a pendulum? Remember that all of the variables are controlled. Identify those that are held constant and those that are allowed to change

2. Figure 2 shows an arrangement set up in a classroom to investigate the influence of soil on the growth of plants. One group of plants (*A, B, C*) is planted in water without soil; the other group (*D, E, F*) is planted in soil and receives water. The height of the plants is the responding variable. All other variables are held constant. Observe the picture carefully and then make a list of all the ways in which the investigator failed to control variables.

3. a. Identify the variables which you infer could influence the occurrence and growth of mold on a slice of bread
   b. Describe how you would control all variables you have identified so that an investigation of the influence of one variable on another could be made

FIGURE 2

COMMENTS ON SELF-EVALUATION

1. a. Your list might include any or all of these factors: Length of the support (string, wire, rod), mass of the

pendulum bob, weight of the pendulum bob, amplitude of the swing (how far it swings to each side), size of the pendulum bob, mass of the support, air resistance, the initial push, and geographic location

b. Yes, the responding variable

c. Your specifications should be quite complete by this time

2. a. The shape of containers is uncontrolled

b. The amount of light is uncontrolled—plants on the right have no lamp over them

c. The quality of light is uncontrolled—plants on the left have some artificial light

d. The temperature is uncontrolled—plants on the right have a radiator beneath the shelf; apparently temperature is measured on the far left of the room

e. The spacing between plants is uncontrolled—plants on the left are crowded together; those on the right are not

f. The circulation of the air is uncontrolled—open windows and fan are on the left

g. The number of plants per pot is uncontrolled

3. a. Your list should include many of the following: Kind of mold placed on the bread, amount of mold placed initially on the bread, past history of the fungus placed on the bread, ingredients of the bread, fungicides in the bread, temperature of the environment, humidity of the room, circulation of the air in the room, amount of light, composition of air, time, length of day and night, geographical location, presence or absence of crust on the bread

b. In your statements, check to see if you described how to manipulate one variable, how to measure the responding variable, and how to hold other variables constant

INTERPRETING DATA

OBJECTIVES

After you have studied this exercise you should be able to

1. *DESCRIBE* in a few sentences the information shown on a table of data or graph.
2. *CONSTRUCT* one or more inferences or hypotheses from the information given in a table of data, graph, or picture.
3. *DESCRIBE* certain kinds of data, using the mean, median, and range; *CONSTRUCT* predictions, inferences, or hypotheses from this information.
4. *DISTINGUISH* between linear and nonlinear relations.
5. *DESCRIBE* the information provided by the slope of a graph.
6. *APPLY A RULE* to find the slope of graphs of linear relations.
7. *NAME* coordinates of points in three-dimensional graphs.
8. *CONSTRUCT* a three-dimensional graph given number triples.

RATIONALE

One of the great strengths of *Science—A Process Approach* is the opportunity it provides for the development of skills that can be transferred to a variety of experiences in and out of school. *Interpreting Data* is such a skill. While the ability to interpret data is essential in science, it is also of vital importance in other disciplines. We are constantly interpreting data when we watch the news on television, when we read weather maps, and when we look at photographs in newspapers or magazines.

Although exercises labeled *Interpreting Data* begin in Part E, the children already have acquired some competence in this process. In Parts A through D, the children have conducted investigations where they have made observations, classifications, and measurements. They make records of their investigations and predict, infer, and interpret from the data collected.

Interpreting Data can be divided into three different areas. One part is basically concerned with data interpretations leading to inferences, predictions, and hypotheses. A second part is concerned with developing skills in the use of statistical measures of central tendency (mean and median) and variation (range). The third part develops skills in the use of probability.

This exercise is primarily concerned with interpreting data to make inferences, predictions, and hypotheses. Before studying this exercise you may wish to refer to the exercise on *Using Numbers* to review the use of statistical measures; also you may wish to refer to the paper on *Probability.* In addition, you might want to review graphing procedures discussed in *Communicating.*

Activity 1 is a general discussion of the use of graphs. Using the mean and median to represent data is covered in *Activity 2. Activity 3* presents data in pictorial form. While few exercises are concerned with this aspect of interpreting data, some practice is included because there are times in scientific investigations when this is the most feasible type of record to present. In *Activity 4,* the concept of the slope of a straight line is applied in interpreting data about the density of materials. Finally, *Activity 5* discusses three-dimensional graphs. Although this discussion might have been included in the exercise on *Communicating,* the instruction relating to the subject is in *Contour Maps, Interpreting Data 8, Exercise p,* Part F. Therefore, it seemed more appropriate to include this subject in this discussion.

This chapter seems long because of the wide variety of data presented. Even so, it is impossible to discuss the interpretation of all kinds of data that will come into an elementary classroom. Your aim, therefore, should be to acquire sufficient competence and experience in describing, inferring, and hypothesizing from data, so that you will habitually do these things with any data you confront.

MATERIALS

graph paper, 3 or 4 sheets

VOCABULARY

linear	coordinate
nonlinear	mean
relation	median
slope	central tendency
range	variation
equation	photosynthesize

Activity 1 — Interpreting Graphs

Suppose someone gave you a graph which showed the height of a plant at various times after planting. (See Figure 1.) How would you describe the shape of the curve in the graph? You might say: The growth curve shows that the plant sprouted on about the fifth day and then grew in increasing amounts each week thereafter for six weeks. At that time, the plant was about 44 centimeters tall.

This description seems all right, but the term *increasing amounts* is not specific enough. To be more specific, you might describe how much the plant grew between equal intervals. For example, Figure 2 gives the data recorded on the graph in tabular form. The third column shows how much the plant grew each week. Now we see that the amount of growth per week increased from 1.3 centimeters the first week to 13.0 centimeters in the sixth week. If you were a botanist looking at these data, you might next ask questions like the following.

1. Why does the plant grow so slowly at first?
2. Why does the amount of growth during each week get larger and larger?
3. What inferences can be constructed in answer to these two questions?

To answer these questions, let's assume you plant more seeds. At one week intervals, you measure the height of a plant. Then you uproot it, dry it in an oven, and weigh the dry plant. You record the data, as in Figure 3.

Complete the third column in Figure 3.

Construct a graph using the data of the first and second columns in Figure 3.

Compare your new graph with the one in Figure 1. Also, compare the changes in height (Figure 2) with the changes in mass (Figure 3) to study the question: Why does the plant grow so slowly at first? The data indicate that in the first week there was little growth in height, and that the mass decreased. Could there be some relationship between plant height and the mass of the dry plant? What inference is suggested?

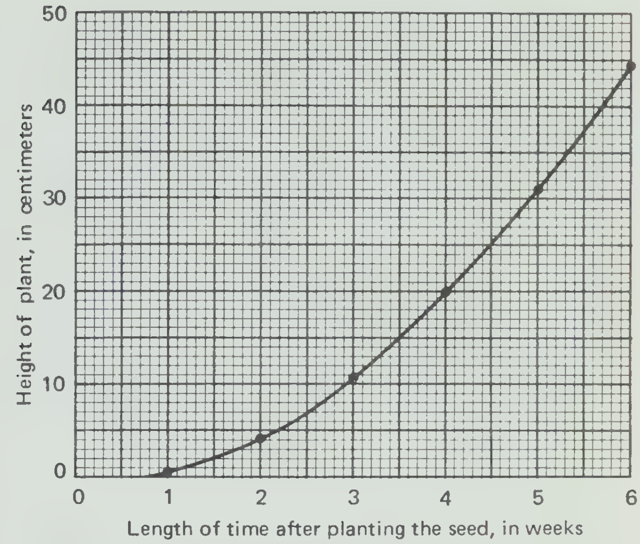

FIGURE 1

Length of time after planting the seed, in weeks	Height of plant, in centimeters	Change in height from one measurement to the next, in centimeters
0	0.0	
		1.3
1	1.3	
		3.6
2	4.9	
		6.1
3	11.0	
		9.0
4	20.0	
		11.0
5	31.0	
		13.0
6	44.0	

FIGURE 2

Question 1

Question 2

You might infer that the plant was diseased, so the mass of the dry plant decreased and the plant did not grow much in height. If this inference is correct, you can then infer that the plant became healthy again during the second week, since both height and mass increased during that time. Or, you might infer that the decrease in mass of the dry plant results from the seed using up food while it grew below the soil's surface.

The increase in the plant's mass after the first week may be explained like this: By the time the plant is one week old, it has grown above the soil's surface and begins to photosynthesize; the change in mass of the plant (after being dried) is a measure of the food the plant has manufactured. You might say that the plant weighs more because it has begun to store food. If there is excess food, you could infer that this extra food would aid the rapid growth in the height of the plant.

Your inferences may or may not be correct, but you can test them. The important point is that you were able to make these inferences as a result of interpreting data.

Length of time after planting the seed, in weeks	Mass of dry plant material (seed, roots, stems, and leaves), in grams	Change in mass of dry plant between successive measurement, in grams
0	1.0	
		______ ?
1	0.5	
		______ ?
2	1.0	
		______ ?
3	2.0	
		______ ?
4	4.0	
		______ ?
5	8.0	
		______ ?
6	12.5	

FIGURE 3

Activity 2 — Describing a Population Using Representative Data

In the hypothetical experiment described in *Activity 1,* you could not, of course, uproot and dry a plant at the end of a week and then plant it again. It must be assumed, therefore, that it was necessary to use a number of seeds to grow many plants, all under the same conditions. Furthermore, we assume that several plants were studied at each stage, and average or representative measurements were taken. In this activity, consider how those representative data were obtained.

Suppose you planted 100 seeds in a large tray and grew the plants for six weeks under conditions as constant as possible. Let's say that you harvested five plants at the end of one week, five more plants at the end of two weeks, and so on, until the end of the sixth week. At each harvest, you measured and recorded the height of each of the five plants, dried the plants in an oven, and then measured their mass. You also dried five unplanted seeds and determined their mass.

Figure 4 lists the measured heights of each of five plants and records the mass of the five dried plants for each measuring period. Continuing this imaginary test, let's assume that you determined the mean height of the plants for each growth period and determined the mean mass of the dried plants for the same period. In the latter case, you divided each total mass by 5. To obtain the mean heights, first you had to add the values and then divide by 5. Your data then looked like those in Figure 5. (Notice that they are the same as those given earlier in Figures 2 and 3.)

Length of time after planting the seeds, in weeks	Height of each plant, in centimeters					Total mass of 5 plants after drying, in grams
0	0	0	0	0	0	5.0
1	1.3	1.2	1.4	1.1	1.5	2.5
2	4.8	5.0	4.5	5.3	4.9	5.0
3	12.0	12.0	12.0	13.0	6.0	10.1
4	20.0	18.0	17.0	25.0	20.0	20.2
5	30.0	29.0	34.0	31.0	31.0	40.2
6	40.0	49.0	43.0	38.0	50.0	62.4

FIGURE 4

Since you have used one number to represent five numbers (what you have done in taking the mean), you should have some notion of how accurately your mean represents the numbers. For example, examine the set of five plants that were two weeks old. The heights of these plants are: 4.8, 5.0, 4.5, 5.3, 4.9 centimeters. First, note that the range (the amount from smallest to largest) is 0.8. The range indicates the amount of variation in the heights of the plants. In this case, the range is large, since 0.8 is about one-sixth as large as the observations themselves.

You can also describe the height of the plants in terms of the median, or middle number. In this sample (5.3, 5.0, 4.9, 4.8, 4.5), the median is the same as the mean, 4.9. This is encouraging because it tells you that the same height (4.9 centimeters) is the representative number of the set in two ways.

Look at Figure 4 and examine the heights of one or more of the other sets of plants (3,4,5, or 6 weeks old) and find the median height for the set as well as the range. How representative are the mean and the median in these cases?

Length of time after planting the seeds, in weeks	Mean height of one plant, in centimeters	Mean mass of one plant, in grams
0	0.0	1.0
1	1.3	0.5
2	4.9	1.0
3	11.0	2.0
4	20.0	4.0
5	31.0	8.0
6	44.0	12.5

FIGURE 5

Question 3

Activity 3 — Interpreting Pictorial Data

In *Activity 1*, we inferred that the increase in the plant's mass was due to the fact that the plants began to photosynthesize and store food after growing for seven days. Suppose the pictorial data shown in Figure 6 had been recorded at the

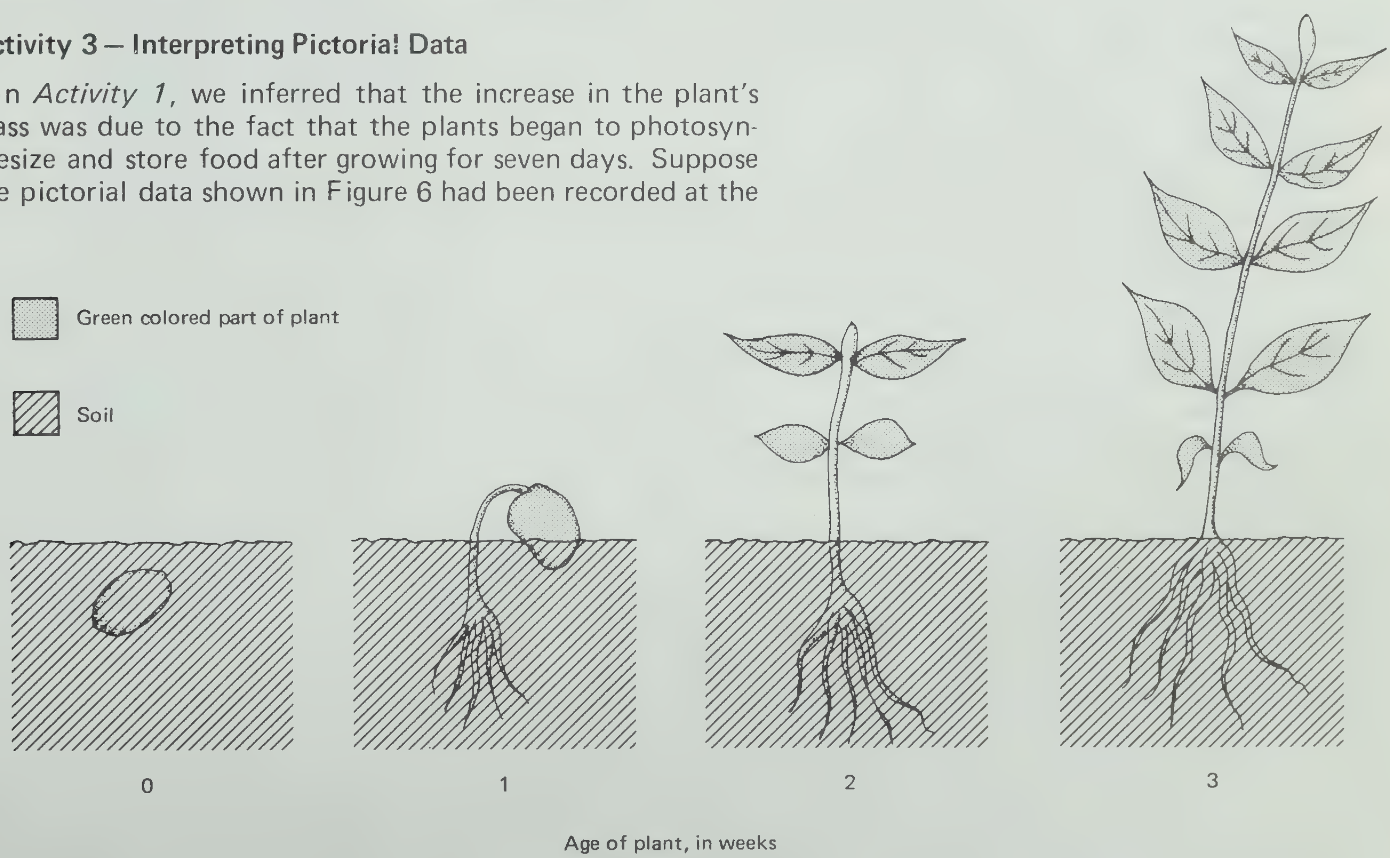

FIGURE 6

time the plants were growing. Does this information support the inference? Yes, it does; you can see that the plant was beginning to become green and was breaking through the soil's surface a week after being planted.

Figure 6 shows the growth form of only one plant. Do you think the other plants appeared the same? You cannot tell from these pictures, but the differences in the data on height and mass at various ages suggest that the other plants would not have appeared exactly the same. Thus, you may infer that the other plants might look different.

Interpreting Data requires you to distinguish between observations and the inferences you make about the observations. It is important not to confuse inferences with observations. Erroneous notions may arise when inferences are accepted as certainty. It is human nature, too often, to accept inferences as certainty if they are not clearly labeled as inferences.

From the data on these seedlings, you might be able to state a hypothesis about the plants such as: Seedlings gain very little in height and actually lose mass during their first week of growth. The data at hand support this hypothesis, but you would certainly want to test the hypothesis by invertigating the growth of other kinds of seedlings.

Number of marbles	Mass in grams
0	0
1	4.3
2	8.6
3	12.9
4	17.2
5	21.5
6	25.8

FIGURE 7

Activity 4 — Linear and Nonlinear Relations

You are, of course, aware of the fact that when some kinds of data are plotted, the points lie on a straight line or very close to a straight line. Such a graph or table of data comprises one way of representing a *linear relation.* Other kinds of data, when plotted, give points that are not a straight line. These kinds of data and their graphs represent a *nonlinear relation.* Figure 1 (in *Activity 1*) shows a nonlinear relation. Graphs of linear and nonlinear relations are common in *Science—A Process Approach* and also in this *Commentary.* Each time you plot data, you should consider whether the relation shown is linear or nonlinear.

Suppose you measured the masses of 1, 2, 3, 4, 5, and 6 marbles and constructed a graph of the data you recorded. The table and graph might be like Figures 7 and 8. How are the number of marbles and the mass in grams related? (The mass is the product of 4.3 and the number of marbles.) Is this relation true for all number pairs in Figure 7? (Yes.) Written as an equation, this relation is expressed:

$$\textit{Mass} = 4.3 \times (\textit{number of marbles}).$$

If you use m for mass and n for number of marbles, the equation would be

$$m = 4.3 \times n.$$

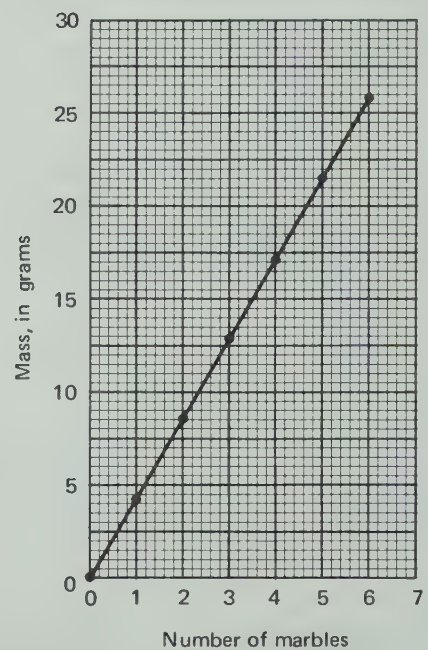

FIGURE 8

The relation between the number of marbles and their mass in grams is expressed as a table in Figure 7, as a graph in Figure 8, and as an equation. Why is this relation called a linear relation? (Its graph is a straight line.)

The number *4.3* by which *n* is multiplied in the equation, is called the *slope* of the graph. You can also call *4.3* the slope of the table or the equation, but the term *slope* is usually used in relation to graphs.

To give you a better idea of how the slope of a line works, try to graph several equations on a single grid. Since you may have forgotten how to plot such equations, let us determine coordinates for the equation, $y = 0.5x$. First, keep in mind that in an equation the numbers on each side of the equal sign must be equal. The equation $y = 0.5x$ indicates that y is equal to one-half of x. For example, if x is *4*, y is *2*, because $2 = 0.5(4)$. One of the points on your graph will therefore have the coordinates (*4,2*). If you like, you might make a table of the number pairs representing the x- and y-coordinates for several points on the graph. Your table might look like this:

x	y	coordinates
0	0	(0,0)
2	1	(2,1)
4	2	(4,2)
6	3	(6,3)

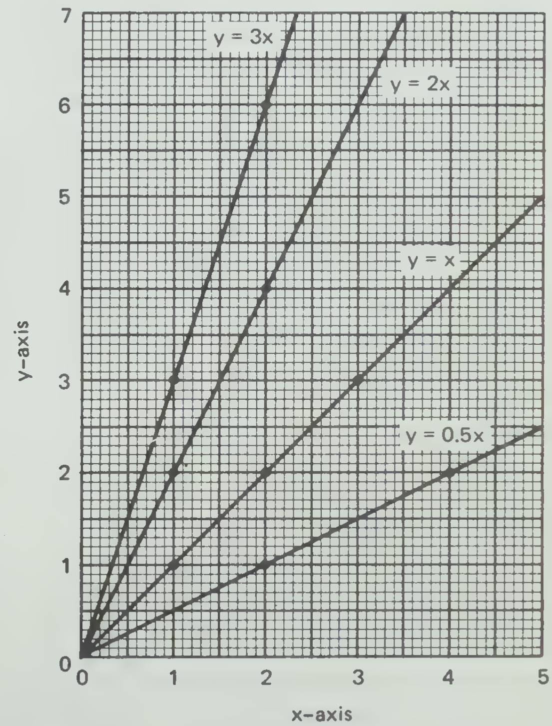

FIGURE 9

Now, find the coordinates for the equations $y = x$, $y = 2x$, and $y = 3x$ and plot your graph. The graphs of the four equations are shown in Figure 9. In the graph of the equation $m = 4.3n$ you called *4.3* the slope. Applying the same principle, what are the slopes of the four lines in Figure 9? What characteristic of the graph appears to be related to the slope? Is it true that the steeper the line, the greater the slope?

Another way of stating the relationship of the slope to the variables (x- and y-axes) is the following:

$$\textit{Slope} = \frac{y\text{-coordinate}}{x\text{-coordinate}}.$$

This definition of slope applies only to lines containing the point (*0, 0*). This ratio is constant for all points on the line except for the coordinates (*0,0*). Examine one of the lines of the graph and note the coordinates of the points plotted along it. You will see that there is the same relationship between each pair. For example, the line $y = 2x$ has these

coordinate points: $(1,2)$, $(2,4)$, $(3,6)$. If you divide the y-coordinate by the x-coordinate in each case, you see that

$$\frac{2}{1} = 2, \frac{4}{2} = 2, \text{ and } \frac{6}{3} = 2.$$

All points on the line produce the slope *2* when the value of the y-coordinate is divided by the value of the x-coordinate. See Figure 10 for an illustration of the slopes of other lines. The simplest way to find the slope of a line is to note what the y-coordinate is when the x-coordinate is *1*.

In the exercise *Density, Experimenting 10, Exercise o,* Part G, it is convenient to use the slope of a line to find density, particularly for pupils who might have some difficulty in dividing decimals. You may wish to refer to that exercise as you work through the following discussion.

You are familiar with the property of matter called mass.* Another property of matter.is density.** Density is the mass per unit volume of any material.

Suppose you want to measure the density of iron. One way to do this would be to weigh and measure the volumes of several pieces of iron. The volume of each piece can be measured by putting it into a graduated container of water and measuring the displacement of the water. For example, one piece of iron placed in a graduated container of water raised the water level 4 milliliters. Hence, the volume of the piece of iron was 4 milliliters. The mass of this piece of iron was 31 grams. The volume and mass of two other pieces of iron were also measured. The measurements are recorded in Figure 11 and plotted on a graph in Figure 12.

What is the slope of the line in Figure 12? Remember, the simplest way of finding the slope is to note what the y-coordinate is when the x-coordinate is *1*. From the graph, you can see that y is about *7.8* when x is *1*, so the slope of the line is *7.8* . Now, recall that the density of a substance is the mass per unit volume. If the unit volume is one milliliter, what is the density of iron? One milliliter of iron has a mass of *7.8* grams as you can see from the graph, so the density of the iron and the slope of the line are the same, *7.8.*

Since the plot of mass and volume for any substance is linear and includes the point $(0, 0)$, it is not necessary to measure the mass and volume of several pieces as described above. All you need to do is plot the point for the mass and volume of one piece of material and draw a straight line through that point and $(0, 0)$. Data for the volume and mass of pieces of lead, aluminum, and glass are given in Figure 13.

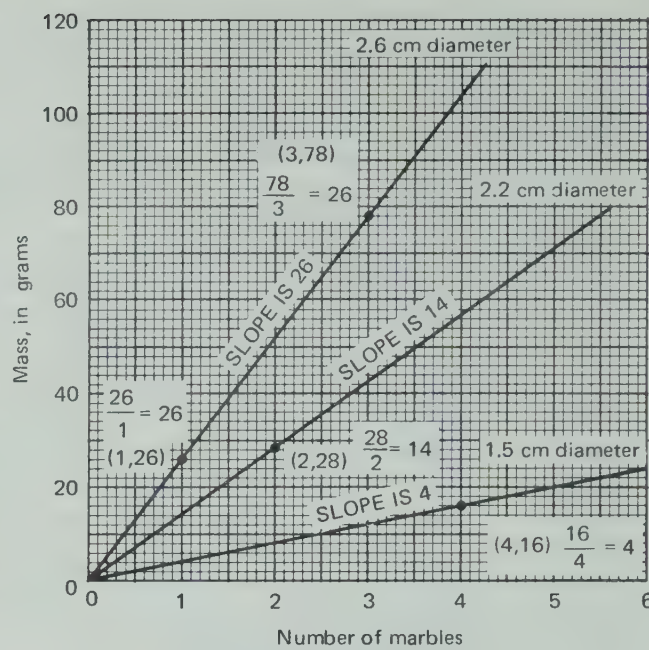

FIGURE 10

Volume of a piece of iron, in milliliters	Mass of a piece of iron, in grams
4	31
7	55
11	86

FIGURE 11

*See background paper, *Mass.*

**See background paper, *Density.*

The line showing the mass-volume relationship for aluminum is plotted in Figure 14.

Find the density of aluminum, using the graph in Figure 14. Question 4

Graph lines for lead and glass, using the data in Figure 13. Question 5

Use the graph to find the densities of lead and glass. Question 6

Do the data in Figure 15 represent a linear or nonlinear relation? Question 7

The best way for you to answer this question is to plot the points and decide whether they lie along a straight line. Another way is to see how the values of *x* and *y* change. As *x* changes by *1* by how much does *y* change?

If you would like to do more work with slope, you may wish to review all the graphs in this book to see if the following hypothesis is supported: In a linear relation, as one variable changes by *1*, the other variable changes by a constant amount.

Piece of metal	Volume in milliliters	Mass, in grams
Lead	3.6	41
Aluminum	3.5	9.5
Glass	5.8	14

FIGURE 13

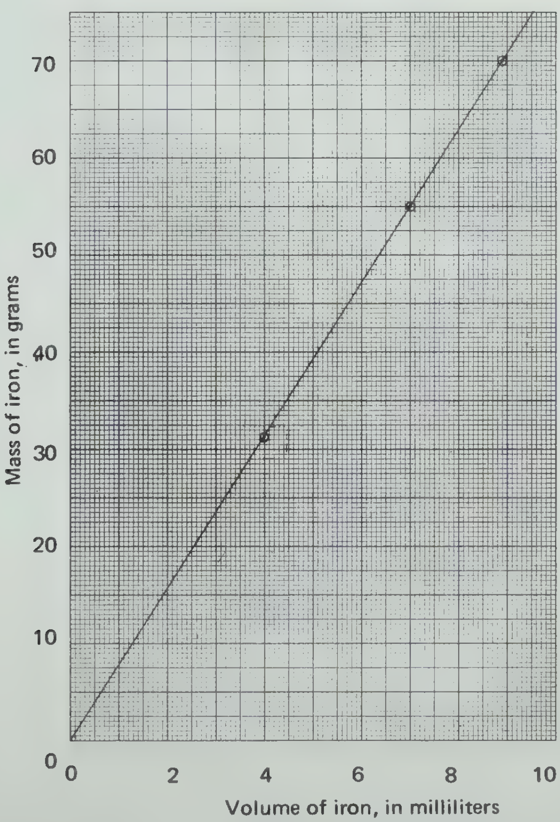

FIGURE 12

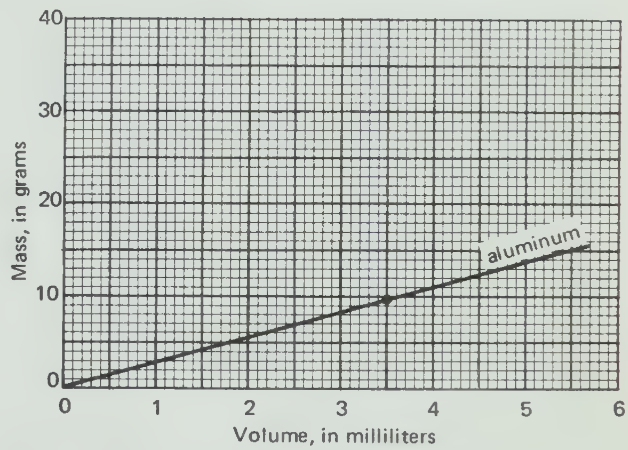

FIGURE 14

x	y
1	2
2	4
3	8
4	16
5	32
6	64

FIGURE 15

Activity 5—Three-Dimensional Graphs

Before you work through this activity; you may want to read through *Contour Maps, Interpreting Data 8, Exercise p,* Part F.

In *Activity 4,* you constructed graphs that had two dimensions, *x* and *y*. Coordinates and graphs are also used to communicate three-dimensional pictures of space, ideas, relationships, or triplet events. Consider a corner of the room you are in, as in Figure 16. Imagine that the lower corner of the room is the origin and that the *x*-axis and the *y*-axis of a graph are the two edges where the walls join the floor. Imagine a grid of lines on the floor, with its origin at the corner. (See Figure 17.) Then imagine a number line along each of the two floor bases, as in Figure 17. Any object on the floor can then be located by stating the two coordinates, (*x,y*).

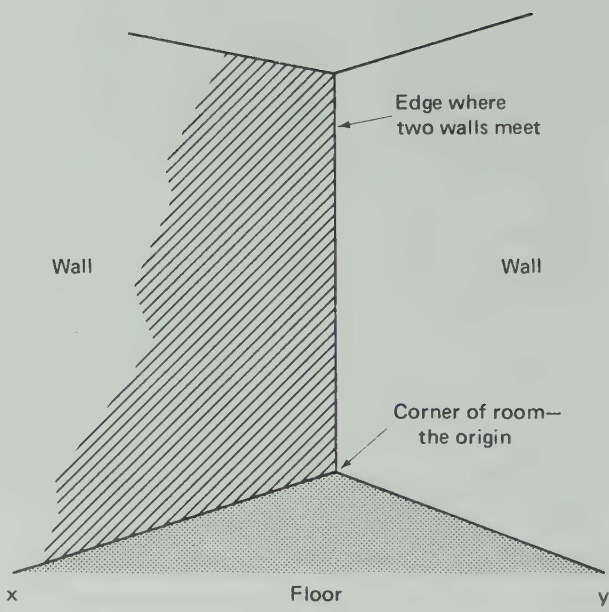

FIGURE 16

Suppose there is an ink stain on the floor. (See Figure 18.) If each space of the grid in the floor is equal to one meter, the inkspot is located by going 2 meters from the origin along the *x*-axis, and then 4 meters out parallel to the *y*-axis. Using *x* and *y* coordinates, you would describe the location of the inkspot by the position (*2,4*).

Suppose you hide the inkspot with a floor lamp, and you want to describe the location of the top of the lampshade. The center of the top of the shade is directly over the inkspot on the floor. First, mark off units up the lamp; then, describe the location of the inkspot and the height of the lamp and put the three distances in one set of coordinates. In the imagined room, shown in Figure 19, the top of the lampshade is 3 meters up. By convention, you put this last distance after the *x* and *y* distances and name it *the distance along the z*-axis. So, the description of the location is (*2,4,3*). The (*x,y,z*) coordinates of the top of the lamp are (*2,4,3*). What is the *z*-coordinate of the inkspot on the floor? Since the inkspot is on the floor, the *z*-coordinate would be zero, and the inkspot would be located by (*2,4,0*).

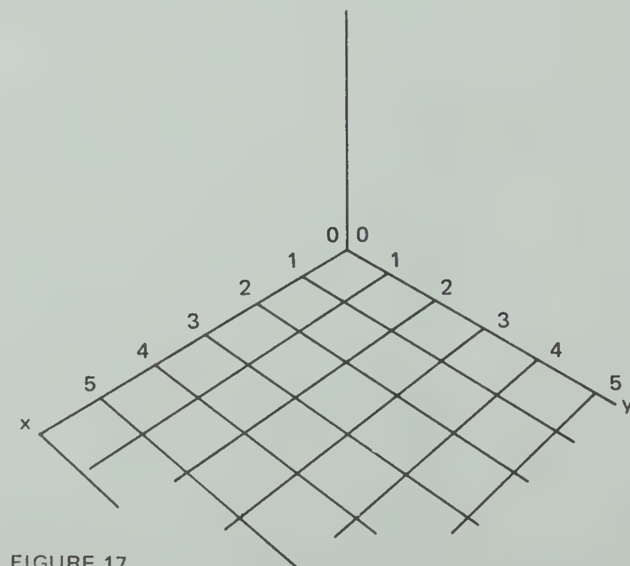

FIGURE 17

Now try another example. (See Figure 20.) Suppose there is an electric outlet on the *yz* wall. How could its location be described in the language of *x-, y-, z*-coordinates? Remember, first ask yourself how far out the object is from the origin along the *x*-axis. Then, ask yourself how far the object is from the origin along the *y*-axis. Which of the following best describes the location of the electric outlet? (*0,0.5,4*), (*0,4,0.5*), or (*4,0.5,4*)?

Question 8

In addition to the lamp, there is a table in the room. Describe in (*x,y,z*) coordinates the location of one or more

Question 9

corners of the table top (marked *A,B,C,* and *D* and the bottom end of two legs of the table (marked *E* and *F*).

The locations of places on the earth are described by three-dimensional coordinates. A city is located at a certain longitude and latitude and at an elevation of so many meters above sea level. When a navigator in an airplane communicates with the control tower to describe his location, he uses three dimensions. And, a submarine captain charts his course in three dimensions. However, he must use distance below sea level instead of distance above sea level. Mining engineers also use a three-dimensional description to locate subsurface features in a fashion similar to that used by submarine captains. If the mining engineer must determine the location and shape of an ore deposit below the ground's surface, he first maps the surface of the ground in two dimensions. He marks one corner of the map by a conspicuous feature, a windmill perhaps, and this becomes the origin. (See Figure 21.) The engineer may then drill several test holes. Examination of the cores brought up from each test hole tells him how far beneath the surface the top of the ore body is. Each test core also tells him how thick the body of ore is at that location. Suppose he encounters ore at each of four drill holes. The depth (in meters) at which the top of the ore body is found is indicated by the third (*z*) coordinate: (*3,1,100*) (*4,1,100*) (*3,4,100*) (*4,4,100*).

This describes a minimum outline of the ore body, when viewed from above at the ground's surface. What shape is the top view of the ore body? Suppose that each drill core that passes through the ore body shows that the ore body is 100 meters thick. Now a picture in three dimensions of the minimum shape and location in the ground of the ore body can be drawn. What is the shape of the ore body?

Question 10

Question 11

What are the *x-*, *y-*, *z-*coordinates of the four bottom corners of the ore body?

Question 12

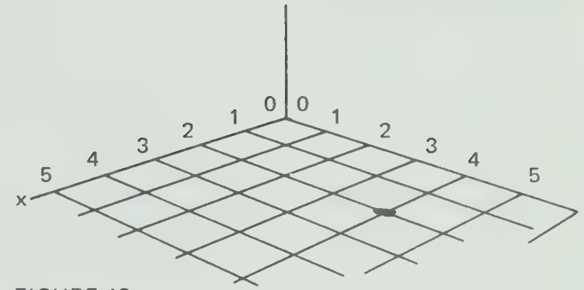

FIGURE 18

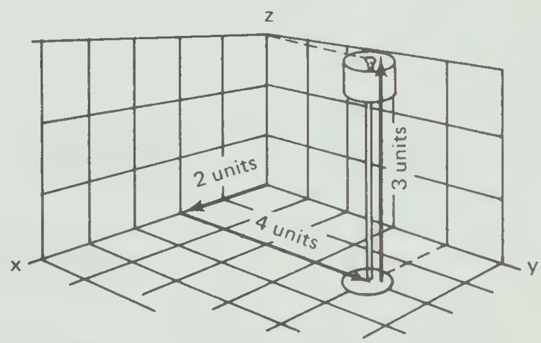

FIGURE 19

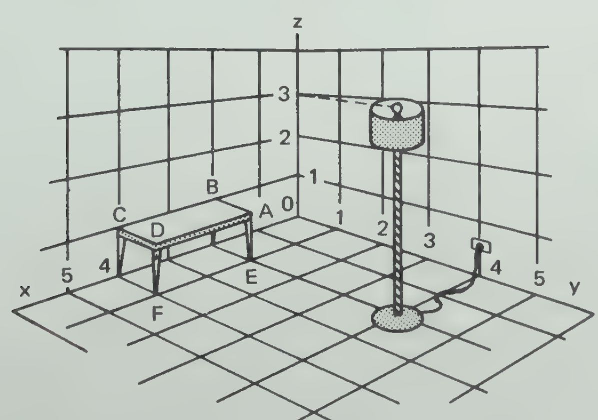

FIGURE 20

COMMENTS ON ACTIVITIES

ACTIVITY 1 (QUESTION 1)

The numbers representing the question marks are: $^{-}0.5$; 0.5; 1.0; 2.0; 4.0; 4.5.

ACTIVITY 1 (QUESTION 2)

A graph of the data should look like Figure 22.

ACTIVITY 2 (QUESTION 3)

The mean of the set of heights for three weeks of age is 11 centimeters, as presented in Figure 5.

$$\left(\frac{12 + 12 + 12 + 13 + 6}{5}\right) = 11$$

The range is 7 centimeters (13 - 6 = 7). The median is 12 centimeters (the middle observation).

The heights of the plants at three weeks of age were unevenly distributed, but the majority of the plants were 12 to 13 centimeters in height; the median represents the observations a little more accurately than the mean.

The mean of the set of heights for four weeks of age is 20 centimeters. The median is 20; the range is 8. The heights are unevenly distributed. The mean and the median are reasonably good representations of the observations.

The mean of the set of heights for five weeks of age is 31 centimeters. The median is 31; the range is 5. The heights are unevenly distributed, but the majority tend to fall between 30 or 31.

The mean of the set of heights for six weeks of age is 44 centimeters. The median is 43; the range is 12. The heights are very unevenly distributed. Either the mean or the median represents the observations equally well.

ACTIVITY 4 (QUESTION 4)

The density of aluminum is 2.7.

ACTIVITY 4 (QUESTION 5)

The graph in Figure 23 shows the lines for lead and glass.

ACTIVITY 4 (QUESTION 6)

The density of lead is 11.4; the density of glass is 2.4.

ACTIVITY 4 (QUESTION 7)

The data in Figure 15 represent a nonlinear relation.

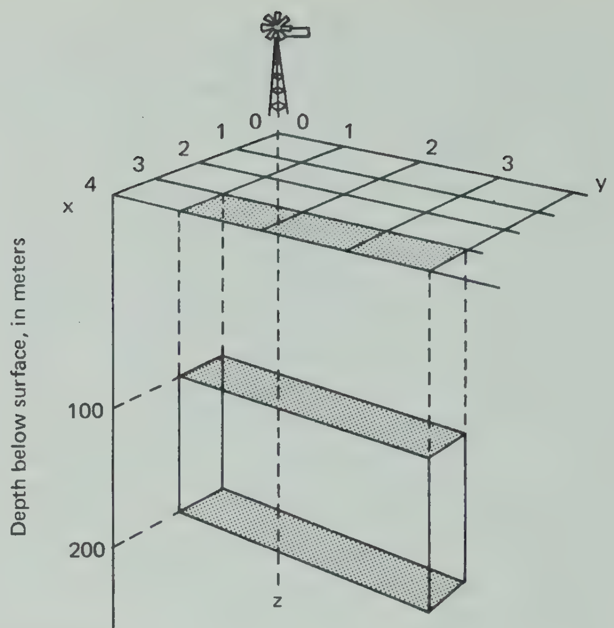

FIGURE 21

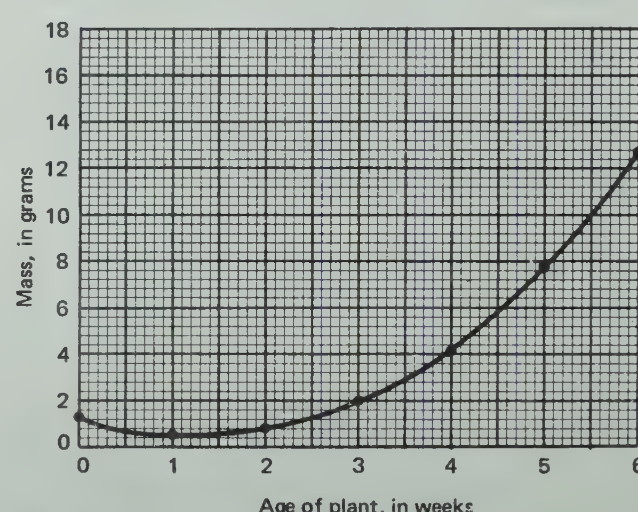

FIGURE 22

ACTIVITY 5 (QUESTION 8)

(0,4,0.5).

ACTIVITY 5 (QUESTION 9)

A is *(2,1,1)*; *B* is *(2,0,1)*; *C* is *(4,0,1)*; *D* is *(4,1,1)*; *E* is *(2,1,0)*; *F* is *(4,1,0)*.

ACTIVITY 5 (QUESTION 10)

A rectangle.

ACTIVITY 5 (QUESTION 11)

A rectangular box or rectangular parallelepiped.

ACTIVITY 5 (QUESTION 12)

The coordinates are: *(3,1,200)*, *(4,1,200)*, *(3,4,200)*, and *(4,4,200)*. (Negative coordinates might have been used on the *z*-axis.)

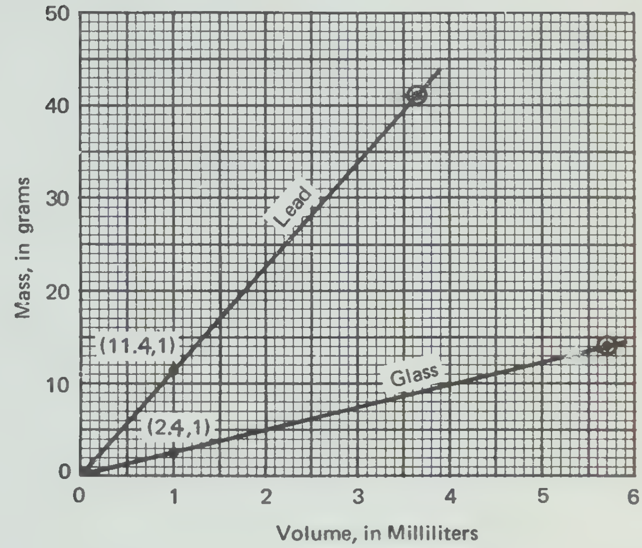

FIGURE 23

SELF-EVALUATION

1. A mixture of ice and liquid water was heated over a candle flame for 20 minutes. The temperature of the mixture was observed and recorded each minute, as shown in Figure 24. It was observed that the ice was all melted after ten minutes.
   A. Describe in a few sentences the information in the table of data.
   B. Construct a point graph of the data.
   C. Is the relationship shown in the graph linear or non-linear?
   D. Construct one or more inferences from the data.
2. The mass and volume of the water-ice mixture were measured at the beginning and end of the investigation. The mass was 100 grams at both times. The volume was 105 milliliters at 0°C and 99 milliliters at 50°C. Does this additional information affect the inferences you made in Question 1D? Construct new inferences on the basis of the additional information.
3. The mass of an object was measured independently by ten different persons with the same set of gram masses and the same equal-arm balance. Their measurements are shown in Figure 25. On the basis of the data, describe the mass of the object.
4. The photograph in Figure 26 was taken by a camera aboard the 1964 Ranger VII space probe. Answer the following questions.

Length of time after starting to heat the mixture, in minutes	Temperature of the mixture, in degrees Celsius
0	0
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	5
12	10
13	15
14	20
15	25
16	30
17	35
18	40
19	45
20	50

FIGURE 24

A. From what side of the picture is the illumination coming? Describe the basis of your inference.
B. Do you infer that the large features in the picture are bumps or craters? Why?
C. Look at the large surface feature *A* in the lower left-hand corner with *B* inside it. Can *A* and *B* both be craters? Can both be bumps? Why?
D. Is the long mark near the largest crater in the upper region of the picture a ridge or a valley? What is the basis for your inference?
E. Look at the surface features *C* and *D*. Does *C* or *D* have steeper sides? What information do you use to make your inference?
F. The photograph shows an area of approximately 52 square kilometers; each side is 7,200 meters long. On the moon's surface, what is the approximate distance between reference marks?
G. What is the approximate diameter of the largest circular surface feature? (Give the diameter in meters.)
H. Select a very small surface feature that you can clearly distinguish without a hand lens. What is the actual diameter of the feature?
I. What inferences can you construct to explain the thin wiggly white line in the lower left corner of the photograph? (It is about 3.5 centimeters in from the left edge and 5 centimeters up from the bottom.)
J. Is the surface hard or soft? Is the surface covered with a layer of dust?

5. State the coordinates of each of the four points (*A, B, C, D*) in Figure 27.
6. Draw a three-dimensional graph and locate *(0,0,1)*; *(2,0,0)*; *(0,3,0)*; and *(2,1,2)*.
7. Construct a three-dimensional point graph of the data in Figure 28.

Person who made the observation	Observed mass of object, in grams
A	9.0
B	10.0
C	10.5
D	9.5
E	10.0
F	12.0
G	11.0
H	10.5
I	10.0
J	7.5

FIGURE 25

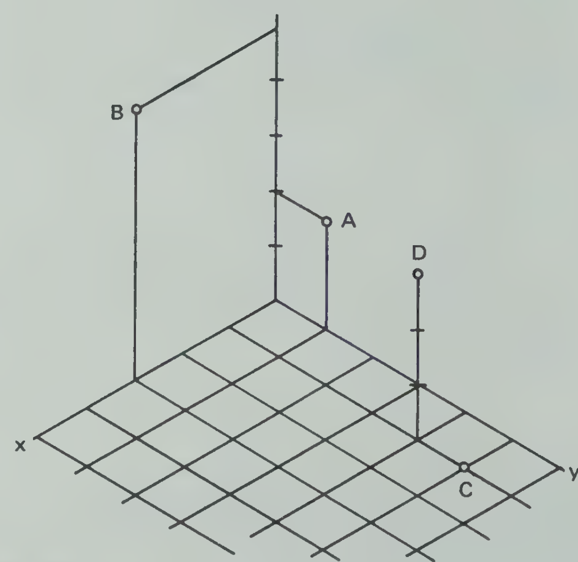

FIGURE 27

Age of plant, in weeks x	Height of plant, in centimeters y	Number of leaves on the plant z
0	0	0
1	1	1
2	2	2
3	4	3
4	8	4

FIGURE 28

COMMENTS ON SELF-EVALUATION

1. A. The temperature was 0° for the first ten minutes and then increased by 5° each minute thereafter up to 20 minutes.
   B. The graph of the data will consist of two line segments. One segment lies on the *x*-axis from *0* to *10*, and the other is a line segment starting upward at *(10,0)* and having a slope of *5*.
   C. The graph shows two linear relationships.
   D. Possible inferences are: When a mixture of water and ice are heated, the temperature remains at 0°C until all of the ice is melted. When water is heated by a

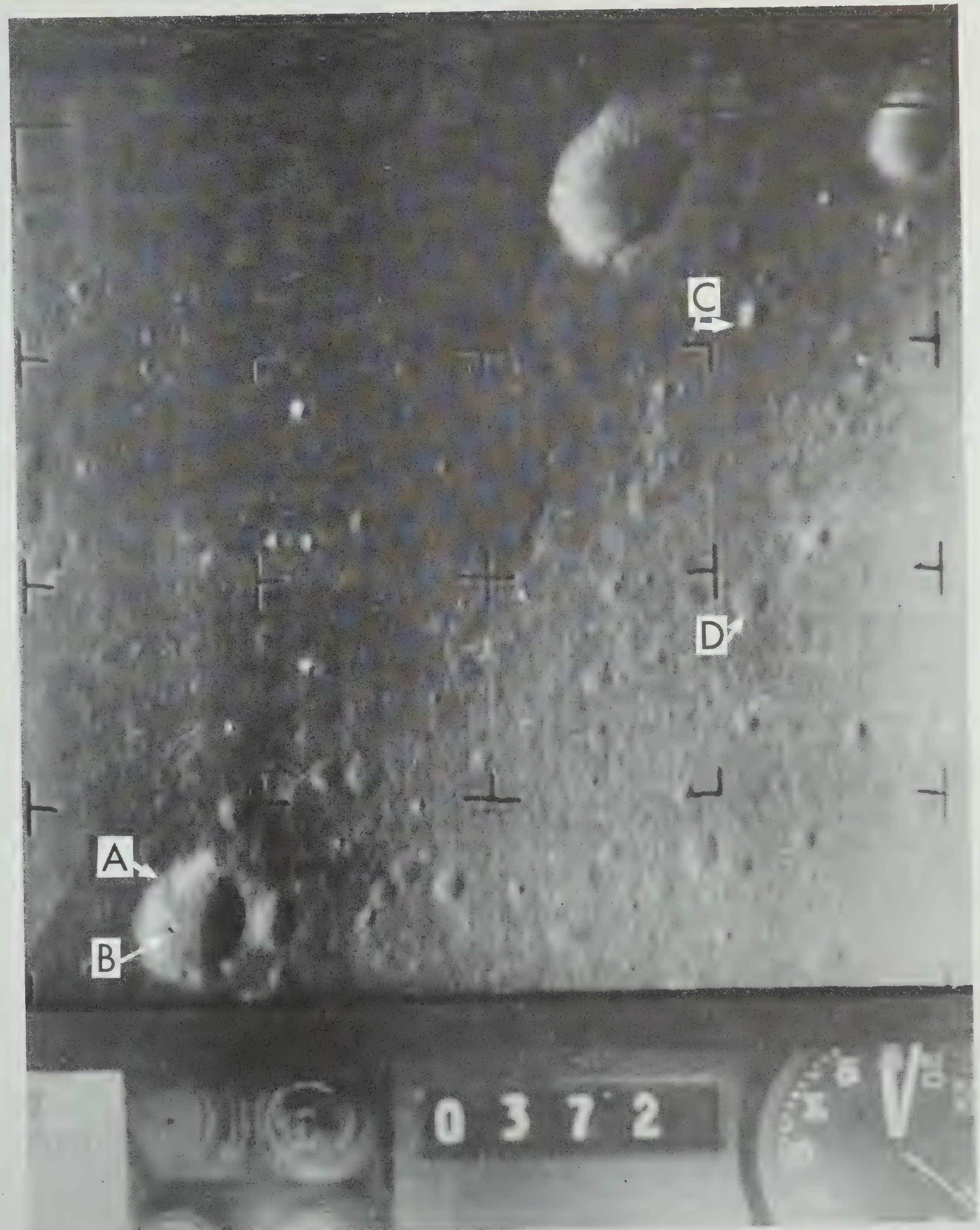

FIGURE 26

Courtesy of Jet Propulsion Laboratory

steady amount, its temperature increases by a constant amount each minute; the relation is linear.

2. Since the inferences in Question 1D did not involve volume, the additional information does not affect those inferences. A new inference might be that the mass of water and ice does not change as the ice is melted, even though the volume decreases.
3. The mean of the ten measurements is *10.0*; the median is *10.0*; the range of the measurements is *4.5*. The object probably has a mass of *10.0* grams. The wide range in the measurements probably reflects the inexperience of some of the subjects making the measurements.
4. A and B. The data in this single picture are not sufficient for an answer to either Question A or B. If you decide the illumination is coming from the right, you will call certain surface features craters and others bumps. But if you decide the illumination is from the left, the surface features you call craters with illumination from the right, will be bumps to you. In order to demonstrate this, use some modeling clay to construct a representation of a part of the moon's surface which contains a bump and a crater. Illuminate the representation from one side and slightly above with a flashlight (or other beam of light). Observe the representation from above.
   C. One is a bump and the other is a crater, for the shadow of *B* is on the left and the shadow of *A* is on the right.
   D. *The shadow on this long mark lies to the left. So, if you infer the large surface feature to be a crater, the long mark must be a ridge. And it must be a valley if the large surface feature is a bump.*
   E. *C* has steeper sides; its shadow is darker than the shadow of *D.*
   F. 1,600–1,700 meters.
   G. 800–1,200 meters.
   I. A piece of hair on the film. A valley or ridge on the moon.
   J. This single photograph presents no data from which inferences can be made about the hardness, softness, or dustiness of the moon's surface.
5. *A* is (*0,1,2*), *B* is (*3,0,5*); *C* is (*1,5,0*); and *D* is (*1,4,3*).
6. See Figure 29.
7. The graph you constructed may look slightly different from Figure 30, depending on the perspective you used in orienting your axes. It is permissible to orient the axes of a three-dimensional graph in different ways. As long as your plot is consistent and the axes labeled, the graph is accurate.

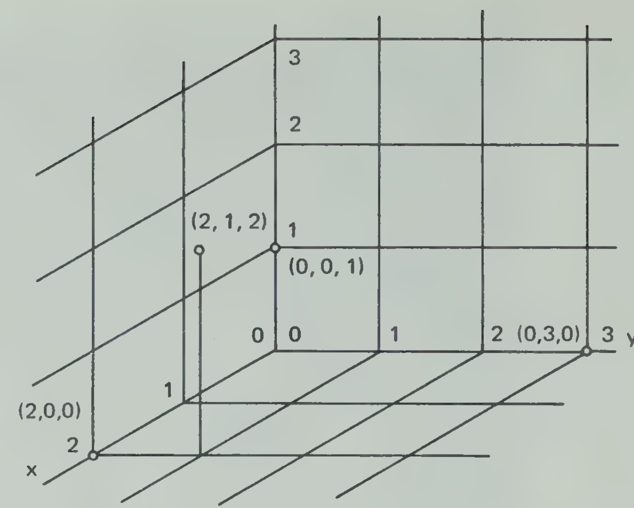

FIGURE 29

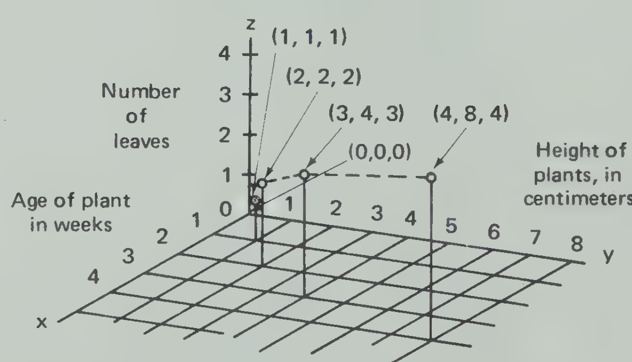

FIGURE 30

FORMULATING HYPOTHESES

OBJECTIVES

After you have studied this exercise you should be able to

1. *CONSTRUCT* a hypothesis that is a generalization of observations or of inferences.
2. *CONSTRUCT* and *DEMONSTRATE* a test of a hypothesis.
3. *DISTINGUISH* between observations that support a hypothesis and those that do not.
4. *CONSTRUCT* a revision of a hypothesis on the basis of observations that were made to test the hypothesis.

RATIONALE

Thinking about observations leads scientists to seek causes for events. To broaden their understanding of their environment, they then generalize their statements of explanation. This process of generalization is what we have called *Formulating Hypotheses.*

In *Science—A Process Approach*, a hypothesis is defined as a generalization that includes all objects or events of the same class. Hypotheses may be formulated on the basis of observations or of inferences. For example, you may observe that a sugar cube dissolves faster in hot water than in cold water. From such an observation, you might formulate the hypothesis that all substances soluble in water will dissolve faster in hot water than in cold water. An example of a hypothesis that is generalized from an inference is as follows: If you invert a glass jar over a burning candle, the candle will continue to burn for a short time and then go out. One of several inferences that you might make to explain this observation is that the candle went out because all of the oxygen in the air

in the jar was used up. A hypothesis based on this inference might be that burning candles covered with glass jars go out when all of the oxygen in the jar is used up.

Research scientists devise tests of hypotheses. Testing a hypothesis that is a generalization from observations consists of making more and more observations of whatever class of objects or events is covered by the hypothesis. For example, the hypothesis that all substances soluble in water will dissolve more quickly in hot water than in cold water can be tested only by mixing many substances that are soluble in water with both hot and cold water and recording their dissolving times. If any substance is found to dissolve in hot water at the same rate as, or more slowly than, in cold water, then the hypothesis is not supported.

Testing a hypothesis that is a generalization from an inference also involves conducting a test which will provide data that will support or not support the hypothesis. In the case of the hypothesis about burning candles under glass jars, it is necessary to test the air in the jar after the candle has gone out to see whether or not oxygen is present. This experiment has been conducted and oxygen is indeed present even after the candle has gone out, so the hypothesis is not supported.

When data are collected that do not support a hypothesis, the hypothesis must either be modified or rejected. In the case of the hypothesis about the dissolving time of substances soluble in water, if some few exceptions are found, the hypothesis might be revised to say: Most substances soluble in water will dissolve more quickly in hot water than in cold water. The hypothesis about burning candles might be modified to state: Candles under inverted jars go out when the amount of oxygen in the air in the jar is reduced to 10%. Or, it might be replaced by a new hypothesis, such as: Candles under inverted jars go out when the amount of carbon dioxide in the air in the jar increases to 3%. All of these hypotheses could be tested by further investigations.

Formulating Hypotheses is introduced in Part E. At first, children learn to distinguish between observations and hypotheses. Later, in Part F, they formulate hypotheses about the effects of temperature on the time it takes a seltzer tablet to dissolve in a liquid. In another exercise in Part F, the children make hypotheses about levers. In this exercise, you will be asked to make hypotheses about objects falling through liquid-filled vials. On the basis of your observations, you will construct a hypothesis which you will test in *Activity 2.*

VOCABULARY

hypothesis
generalize
thinness (or thickness) of a liquid
viscous
viscosity

MATERIALS

Plastic vials with caps, 4
Various liquids such as water, corn syrup, cooking oil
Various solid objects such as marbles, metal spheres, pebbles

Activity 1—Constructing a Hypothesis

In the exercise *Viscosity, Experimenting 11, Exercise p,* Part G, the children observe the apparatus shown in Figure 1a. Each of the vials is full of a liquid, and each contains an object that appears to be ellipsoidal. The caps of the vials are fastened firmly into holes in a wood strip. When the vials are inverted, as in Figure 1b, the objects fall through the liquids at different rates. Some of the observations that may be made are:

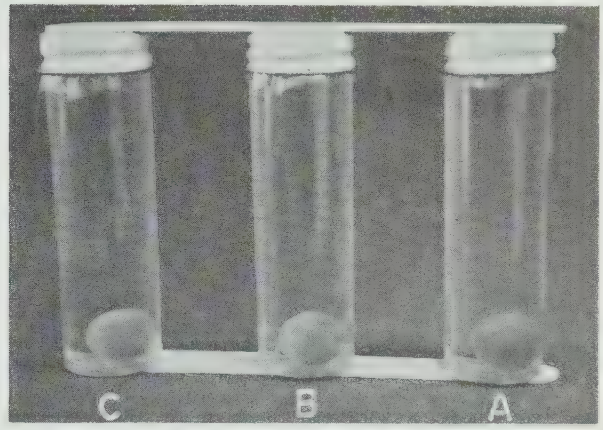

FIGURE 1a

1. The object in Vial *A* falls fastest and the one in Vial *B* slowest
2. The object in Vial *A* is red, in Vial *B,* green, and in Vial *C,* blue
3. The vials have the same shape and size. The liquids are colorless
4. Each vial has a small air bubble in it. The air bubbles move up as the objects move down. The bubble in *A* rises most rapidly, and the bubble in *B* least rapidly

Write several inferences that might account for these observations. After you have made your inferences, generalize one of them into a hypothesis. As you construct your hypothesis, keep in mind that you are going to construct and demonstrate a test of it in *Activity 2.*

Question 1

Activity 2—Testing a Hypothesis

What you do in this activity depends entirely on what hypothesis you constructed in *Activity 1.* Your hypothesis will also determine what materials you will need to carry out your test. You will almost certainly need screw or snap cap plastic vials and one or more liquids (water, corn syrup, cooking oil, and so on). Objects you may want to try might include marbles of various sizes, metal spheres (shot), and pebbles.

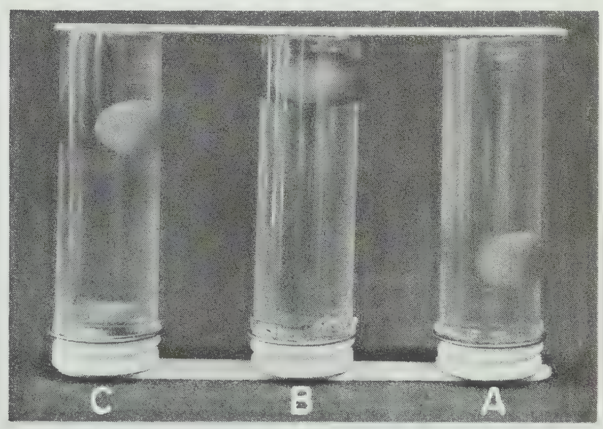

FIGURE 1b

Question 2

Plan and execute your test carefully. Remember that for best results, you should control all variables. You should identify the manipulated and responding variables, and plan to hold all other variables constant.

After you have carried out your test and collected and recorded your data, you should interpret your data and decide whether or not your observations support or do not support your hypothesis. If your hypothesis is not supported, revise it to take account of your new observations. When you have

completed the activities read the following *Comments on Activities.*

COMMENTS ON ACTIVITIES

ACTIVITY 1 (QUESTION 1)

There are many inferences you might make. Here are a few.

1. The objects have different masses. The object in *A* is the heaviest and the object in *B* is the lightest of the three
2. Though the objects appear to have approximately the same size, their sizes actually differ a little. Object *B* is the smallest and Object *A* the largest of the three
3. There is a different liquid in each vial. The liquid in *B* is thickest and that in *A* is the thinnest

Each of these inferences could be generalized into a hypothesis. Here is a hypothesis from Inference 1: The rate at which an object falls through a liquid depends on its mass. Given two objects of the same size but different mass, the heavier one will fall through a particular liquid faster than the lighter one.

ACTIVITY 2 (QUESTION 2)

Suppose you want to test the following hypothesis. Objects of the same size, shape, and mass fall faster in thin liquids than in thick ones.

The manipulated variable is the *thinness* or *thickness* of the liquid. These terms are not commonly used by scientists to describe properties of liquids, though they are frequently heard in everyday speech. They should be defined operationally at the time that the test of the hypothesis is being constructed. Here is one possible operational definition:

> Pour 50 milliliters of the liquid into a 100-milliliter beaker. Invert the beaker and hold it upside down for 10 seconds. Right it and measure the amount of liquid that remains in the beaker. The greater the amount of liquid remaining, the thicker the liquid.*

To test the hypothesis, prepare three or more solutions of different viscosities. These might be water, and 10%, 20%, and 30% sugar solutions. Test the solutions and order them by viscosity. Take four identical vials and fill each with one of the solutions. Then, take four identical marbles and place

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*This is a rough measure of a property of liquids called *viscosity*. The more *viscous* the liquid, the more slowly it flows from a container.

one in each vial. Screw the cap on each vial. Invert the vials and compare the rates at which the marbles fall through the liquids. If the rate of fall is slower in the more viscous liquids, the hypothesis is supported. If not, the hypothesis will have to be revised or discarded.

SELF-EVALUATION

You have already constructed a hypothesis and constructed and demonstrated a test of it in *Activities 1* and *2.* From those experiences, you have probably already evaluated your success with *Objectives 1, 2,* and *3,* and possibly *4.* Here you can further test your success with *Objectives 3* and *4.*

1. The data shown in Figure 2 were collected in a test of the following hypothesis: *All smooth solid spheres roll down an inclined plane in the same time interval. The diameter of the sphere or the material of which it is made does not affect its rolling time.*

Composition of sphere	Diameter of sphere, in millimeters	Rolling time, in seconds	Mean rolling time, in seconds
Glass	24	2.0, 2.1	2.05
Glass	15	2.0, 2.1	2.05
Glass	10	2.3, 2.3	2.3
Glass	6	2.4, 2.4	2.4
Glass	4	2.6, 2.8	2.7
Steel	24	2.0, 2.1	2.05
Steel	10	2.3, 2.2	2.25
Steel	4	2.6, 2.6	2.6
Steel	3	3.2, 3.0	3.1
Plastic	20	2.1, 2.0	2.05
Plastic	6	2.3, 2.5	2.4
Plastic	3	3.0, 3.0	3.0

FIGURE 2

Smooth solid spheres of various sizes and made of different materials were rolled one at a time down an inclined plane made of smooth cardboard. The plane was one meter long, and the elevated end was 6.5 centimeters above the table. Each sphere was rolled twice. The rolling time was measured with a stopwatch that was accurate to 0.1 second. Examine the data in Figure 2 and list those

data, if any, that support the hypothesis, and which data, if any, do not support it.

2. If any of the data do not support the hypothesis, write a revision of the hypothesis.

When you have completed the *Self-Evaluation*, read the following *Comments on Self-Evaluation.*

COMMENTS ON SELF-EVALUATION

1. The data can be interpreted by examining the table and comparing rolling times for marbles of the same size made of different materials, and for marbles of different sizes made of the same material. But there are no triples of data for marbles of the same size made of each of the three materials, so the data might better be compared by graphing them. (See Figure 3.) The rolling times plotted are the means of the two rolling times given in the table. From the graph, it is clear that the composition of the sphere has no significant effect on rolling time. Hence, that part of the hypothesis is supported. Likewise, the rolling time is not affected by the diameter if the diameter is greater than fifteen millimeters. However, for diameters less than fifteen millimeters, the rolling time on a cardboard inclined plane is affected by the diameter.
2. The hypothesis can be revised in various ways. Here is one way: The time for a smooth solid sphere to roll down a smooth cardboard inclined plane is not affected by the composition or the diameter of the sphere, provided the diameter is greater than fifteen millimeters.

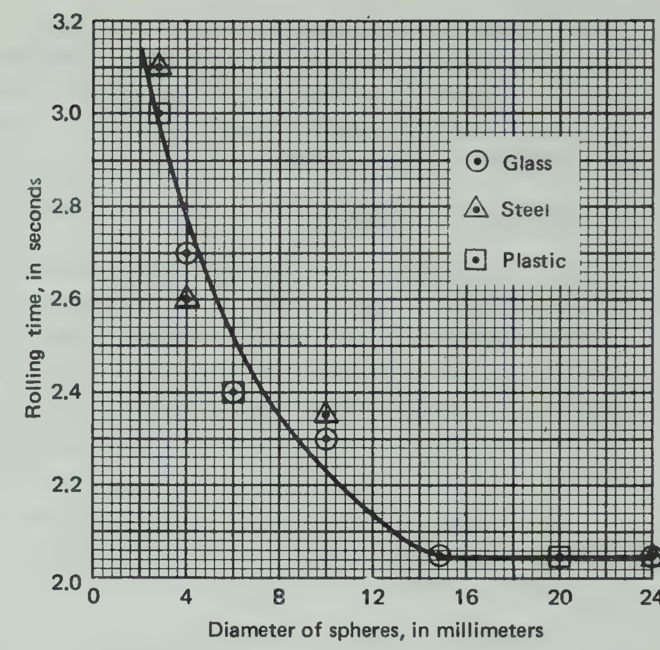

FIGURE 3

DEFINING OPERATIONALLY

OBJECTIVES

After you have studied this exercise you should be able to

1. *DISTINGUISH* between operational definitions and nonoperational definitions.
2. *IDENTIFY* variables or words for which an operational definition is needed, given a hypothesis, inference, question, graph, or table of data.
3. *CONSTRUCT* an operational definition which adequately describes a procedure, concept, object, or property of an object in the context in which it is used.

RATIONALE

Words are the currency of much human communication, and it is through verbal exchange, either written or oral, that much of our teaching and learning occurs. Our basic philosophy is that effective learning takes place when the student is actively involved in developing the process skills that form the central theme of the material he is studying. In all the processes, teacher-pupil and pupil-pupil interaction are vitally dependent on the precise use of terms. Competence in defining operationally is of critical importance in the precise use of terms in communication about investigations and experiments.

A measure of the cultural level of a society lies in the sophistication of its vocabulary; the extent of the application of that vocabulary contributes to the continuation and advancement of that society. In fact, as the complexity of societal operations increases, so does the use of more and more specialized words and terms. In our own society, we find that specialized groups—whether they be nuclear physicists or hip-

pies—develop their own "jargon." The meanings of existing words may be changed by such groups to express entirely different ideas. It is in this context of communication and change, then, that defining operationally takes on its significance as a process skill. In *Defining Operationally,* the pupils will be expected to define terms in the context of their own experiences.

A definition that limits the number of things to be considered and, at the same time, specifies the essential experimental evidence to be gathered is more useful than a definition that encompasses all the conceivable variations that might be encountered. More than one operational definition may be used in a particular situation; you should encourage children to propose and use alternative definitions.

At first, the program stresses the *use* of operational definitions in testing hypotheses and inferences. Second, it stresses the *formulation* of operational definitions that may be useful in constructing hypotheses and inferences. A careful study of the Hierarchy Chart will give you an overview of the importance of recognizing, using, and constructing operational definitions as a tool in the solution of scientific problems. By the time the pupil reaches Part G, he is expected to formulate and use such definitions routinely. For example, in *Resolving Power of the Eye, Experimenting 3, Exercise h,* Part G, pupils are asked to formulate hypotheses about the resolving power of the eye as measured by the distance at which two pinholes can be seen as separate. They will construct operational definitions of terms as one of the steps in testing their hypotheses.

In the development of exercises for the *Defining Operationally* process, we discovered that the physical and biological sciences impose somewhat different criteria in judging what is and what is not an operational definition. Physical scientists state operational definitions in terms of "what you do or what *operation* you perform" and "what you observe." For example, an operational definition of oxygen might be:

> Oxygen is a gas that causes a glowing splint to burst into flame (what you observe) when the splint is placed (what you do) in a container of the gas.

If a child wishes to decide if a gas is oxygen, he can use this definition. He knows exactly what to *do* and what to *observe.* In contrast, consider this definition of oxygen.

> Oxygen is an element composed of atoms having atomic number 8 and atomic weight 16.

This definition would be quite useless to the child in trying to identify the gas in a container. He would not know what to do or what to observe. It is a good example of a non-operational definition.

Most of the *Defining Operationally* exercises are from the physical sciences, and in these exercises, the *what you do* and *what you observe* criteria should be applied. In Parts E, F, and G, there are *Defining Operationally* exercises concerned with electric circuits and their parts, analysis of mixtures, true north, mass, two common gases (oxygen and carbon dioxide), and temperature and heat. Also, in Part G, the need for defining operationally arises in most of the *Experimenting* exercises with a physical science setting.

For biologists, on the other hand, operational definitions are descriptive. In Part E, the pupils make investigations that lead to an operational definition of a biological cell, and in Part F they operationally define parts of plants. One example from the latter is as follows.

> Petiole: The stem-like portion of some leaves which connects the leaf blade to the stem; may be as long as the leaf blade or much shorter.

Assuming that stem and leaf have been defined operationally, (as they have been in the exercise), the pupils have no difficulty in identifying the petioles of a plant from this definition. An examination of the definition shows that *what you observe* has been clearly stated but *what you do*, other than observe and apply other operational definitions, is not specified and indeed is not necessary.

So long as you recognize this difference in the requirements of operational definitions for the physical and biological sciences, no problems should arise for you. In a number of situations in elementary school science, a descriptive definition is adequate. These situations usually arise in content concerned with descriptive biology.

In the intermediate grades, the pupils cannot, of course, be expected to formulate operational definitions that would be satisfactory for the study of science in college or for investigations of mature scientists. What they must do is formulate definitions that are satisfactory for their purposes so that they can make themselves entirely clear to their peers, their teachers, and their parents. If possible, their operational definitions should include *what you do* and *what you observe.* It also will be important for them to learn that there can be more than one satisfactory operational definition for their purposes, as well as for science at a more sophisticated level.

This exercise illustrates how operational definitions are used in everyday situations and also gives you practice in identifying and constructing operational definitions.

VOCABULARY

operational definition

MATERIALS

No materials are required for the study of this exercise.

Activity 1—Operational Definitions in the Law

The following conversation illustrates how we may get involved with operational definitions of terms in everyday situations.

"You say I was speeding?" said Sam Smith.

"Yes, you exceeded the speed limit of fifteen miles per hour in that school zone. I will have to give you a ticket! You were driving at an unsafe speed."

"But the children are all in school and no one was along the street. How could my speed have been unsafe?"

"The law is the law. Here is your ticket."

Since the law defines "speeding in a school zone" as: *Driving a car in excess of fifteen miles per hour in a school zone which is marked by appropriate signs,* the officer is correct. The law tells the officer what to observe and what to do. All he has to do is observe a car inside a marked school zone and measure the speed of the car; if the speed exceeds fifteen miles per hour, the car is speeding and the driver gets a ticket.

Mr. Smith used his own operational definition in his futile debate with the policeman. Sam's definition of speeding is: *In a marked school zone, a car is speeding only if the speed exceeds fifteen miles per hour when children are near the street.* It's an operational definition because it tells you what to do (check your speedometer) and what to observe (the children near the street).

Another operational definition, but one which is quite unsuitable, defines speeding in a school zone on the basis of what has happened after the fact: *If your car hits a child in a school zone and hurts him, you are speeding in a school zone.* This is an operational definition because it tells you how to recognize what is being defined. But this definition tells you that you are speeding only after you have done it, not before. If the child is hurt, the car is speeding. But if the child gets up and walks away, the car is not speeding. For obvious reasons, this operational definition of speeding in a school zone has not been used!

Mr. Smith's plight illustrates several important ideas to keep in mind when teaching operational definitions. Some of these are listed here and you may think of others.

1. There is a recognized need for the definition because of lack of agreement, or ambiguity in the meaning of a term
2. The definition is based on observable properties or operations which can be performed by the person using the definition
3. The definition describes what you are to observe and perform
4. There may be more than one operational definition of a term
5. One definition may be more adequate or useful than another, depending upon the situation in which the definition is used

Activity 2 — Identifying a Need for an Operational Definition

In the exercise, *Conductors and Nonconductors, Formulating Hypotheses 2, Exercise j,* Part E the children formulate this hypothesis: Good conductors of electricity are also good conductors of heat. If they want to tell their classmates, friends, or parents about this hypothesis they must be able to define operationally the terms involved in the hypothesis. What words or terms in the hypothesis should the pupils be able to define operationally? Formulate your own answer to this question, and then compare your answer with the acceptable responses given at the end of this exercise. Question 1

Activity 3 — Identifying Operational Definitions

Pupils will have experiences that will reveal to them a need for defining operationally in a variety of situations. These situations might be classified by the nature of the terms to be defined. The following list provides one classification, with an example of each.

1. Substance: oxygen
2. Concept: pressure
3. Unit of measure: small calorie
4. Process: weighing
5. Property (qualitative): metallic luster
6. Property (quantitative): density

Operational and nonoperational definitions of oxygen were given in the *Rationale.* Two definitions of each of the other terms are given in the following paragraphs. Choose which is the better operational definition, and be prepared to defend your choice. The defense, of course, should not be difficult, because you will choose the definition that clearly states *what you perform and what you observe.* The less satisfactory definition may be one you would find in a dictionary. Question 2

Pressure:

(a) Measure the total force and divide the measurement by the measurement of the area on which the force is applied. The quotient is a measure of the pressure

(b) How hard something is pressing

Small Calorie:

(a) A unit of heat

(b) The amount of heat that increases the temperature of 1 milliliter of water 1 Celsius degree

Weighing:

(a) Measuring how heavy something is

(b) Measuring the extension of a calibrated spring scale when an object is attached to the lower end of the spring

Metallic Luster:

(a) An object has metallic luster if it is opaque and reflects light that is white, yellow, or copper-colored. For example, silver, gold, and copper have metallic luster

(b) Shininess

Density:

(a) The quotient of the mass of an object in grams and the volume of the object in milliliters

(b) Heaviness

In the examples considered so far, it has not been difficult in the more satisfactory definitions to identify what you perform and what you observe. Now consider some other types of operational definitions that may be satisfactory in some situations, although what you perform may not be so clearly stated.

1. Weed:
   A plant which is growing where it was not planted intentionally
2. Rain:
   Drops of water falling from a cloud in the sky
3. Earthworm:
   An animal that lives underground, is pinkish in color, soft and damp to touch, and is cylindrical in shape when held out straight
4. Bird:
   An animal which walks on two legs and flies

You can probably think of classroom situations in which these definitions could be considered satisfactory. You and

your children could probably also think of additional phrases, not necessarily involving what you perform, that would make them more satisfactory.

One of the weaknesses of these definitions is that they are not exclusive enough for class investigations. Consider weed, for example. After all, forests are usually not planted by man, but such forests are usually not considered weeds. Some flowers seed themselves and come up the next year, but they are not then weeds for this reason. As another example, a bat fits the definition of a bird, but bats are not considered to be birds. Try your hand at improving the operational definitions of weed, rain, earthworm, and bird.

Now, consider three definitions of the term, *good conductor of electricity.*

A. A good conductor of electricity is any object which can be used to complete an electric circuit
B. A good conductor of electricity is any object through which electricity flows easily
C. A wire is removed from an arrangement of batteries, wires, and light bulb in which the bulb is glowing, and the light bulb goes out; if an object is used to replace the wire and the light goes on again, the object is a good conductor of electricity

Which definition, *A, B,* or *C,* would you choose as the best operational definition? Question 3

Activity 4 — Defining Operationally, from a Child's Point of View

In *Science—A Process Approach,* you ask children to make operational definitions on the basis of their own observations, thoughts, and experiences. You must not expect their definitions to be the same as yours. After all, your experience is far more extensive than theirs. A definition which seems adequate to a child, at least according to his experiences and observations, may not seem adequate to you. Is the child wrong? Not from his point of view. To require him to use your definition, which is not based on his experience, would be to defeat a major aspect of the process approach to science.

As a child continues his study, he will meet progressively more complex terms which need to be defined. He will also need to revise definitions he has made previously. To him, an operational definition can only be stated in terms of activities *he* has done: using words, ideas, skills, and operations which he has mastered. An operational definition is a "doing definition." The skill is one to be developed gradually through the child's continuing experience as he acquires a higher level

of competence in the science processes. When his definition is inadequate, let the child discover this for himself.

No new task is given for you to perform in this activity, but the caution provided here is well worth the attention of an activity. At the beginning, operational definitions will be given to the child, but at the earliest possible stage he should begin to construct his own. Only as he is able to define terms he uses as operations to be performed, even though the operation is only careful observation, will he be able to conduct his own investigations to find answers to his questions.

COMMENTS ON ACTIVITIES

ACTIVITY 2 (QUESTION 1)

Did you suggest that the children must define what they should do or observe to determine whether or not an object is a *good conductor of electricity* and a *good conductor of heat?* If you did, you have acceptably achieved *Objective 2* of this paper. Perhaps you also indicated the need for definitions of *electricity* and *heat.* These terms could also be included but, *good conductors* of heat and electricity can be defined without defining electricity and heat. (See, for example, the answer to Question 3.)

ACTIVITY 3 (QUESTION 2)

1. Pressure (a)
2. Small calorie (b)
3. Weighing (b)
4. Metallic luster (a)
5. Density (a)

The choices are easy to defend, as you will surely agree.

ACTIVITY 3 (QUESTION 3)

The definition *A* is an operational definition, provided "complete an electric circuit" has already been defined operationally; this definition does tell you what to do. Definition *B* is poor because it does little more than define "good conductor of electricity" in the nearly synonymous words "electricity flows easily." This is similar to a dictionary definition. Definition *C*, though somewhat cumbersome, is the best of the three definitions, because it tells you what you do and what you observe. With this definition, anyone should be able to test objects and determine which ones are good conductors of electricity. Note also, that this definition avoids a need for defining the term *electricity.*

SELF-EVALUATION

1. In each of the following statements, identify the words for which there is need of an operational definition.

   A. A long pendulum swings more slowly than a short one
   B. A flower is a group of specialized leaves
   C. Metals carry electricity better than nonmetals

2. Identify which of the following are more appropriate operational definitions for use in grades five and six.

   A. (1) Ice is a solid made up of a three-dimensional network of water molecules
      (2) Ice is a solid that changes to a liquid at 0°C

   B. (1) Equal masses: two objects that balance each other on an equal-arm balance
      (2) Equal masses: two objects that weigh the same

   C. (1) Newton: a unit of force in the metric system
      (2) Newton: the force required to give a one-kilogram mass an acceleration of one meter per second

3. State an operational definition of each of the following that you think would be appropriate for a class in grades five and six.

   A. Rowing (as in a boat)
   B. Seed
   C. Cube
   D. Hot
   E. Speed

COMMENTS ON SELF-EVALUATION

1. A. Pendulum, and *swings more slowly*
   B. Assuming you know what *leaves* are, the word *specialized* does not tell you what particular kind of leaves to look for; that is, *specialized* in what way?
   C. Metals, and/or nonmetals; electricity; carry

2. A (2), B (1), C (2)

3. These definitions are from a dictionary. You may be able to improve them, but in any case, they serve for comparison with the operational definitions you have constructed.

   A. Rowing: Propelling a boat with oars along the surface of water

B. Seed: A part of a plant that is produced from the flower and that grows into a new plant when it is planted
C. Cube: A three-dimensional object that has six faces. All faces are squares of the same size
D. Hot: Having a high temperature relative to the normal temperature of the human body
E. Speed: How far an object moves in a measured time, or kilometers an object moves in one hour, or meters an object moves in one second

EXPERIMENTING

OBJECTIVES

After you have studied this exercise you should be able to

1. *IDENTIFY* the variables to be controlled, *CONSTRUCT* operational definitions as needed, *CONSTRUCT* and *DEMONSTRATE* a test, and collect and interpret data given a testable hypothesis. *CONSTRUCT* a report of the experiment, including a statement about whether the data support the hypothesis.
2. *CONSTRUCT* a question to be answered, *CONSTRUCT* a test that will provide data to answer the question, *IDENTIFY* variables to be controlled, *CONSTRUCT* operational definitions, *DEMONSTRATE* the test, and collect and interpret data, given a set of observations. *CONSTRUCT* a report of the experiment.

RATIONALE

Experimenting is the process that encompasses all of the basic and integrated processes. An *Experimenting* exercise usually begins with observations that suggest questions to be answered. Sometimes, but not always, the experimenter formulates a hypothesis from the question or questions. Whether he formulates a hypothesis to be tested, or simply decides to construct a test to answer a question, the succeeding steps involve identifying the variables to be controlled, making operational definitions, constructing a test, carrying out the test, collecting and interpreting data, and sometimes modifying the hypothesis that was being tested.

All the *Experimenting* exercises are in Part G, beginning after all of the behaviors of the other integrated processes

have been introduced and practiced. Each *Experimenting* exercise combines two or more of the behaviors of the other processes into sequences that become elements of the *Experimenting* hierarchy. The terminal behavior described in the *Experimenting* hierarchy is, of course, the complete sequence of behaviors involved in conducting a scientific experiment.

The two activities in this exercise serve as a self-appraisal.

VOCABULARY

isopropyl alcohol

MATERIALS

Pencil, 1
Tile floor (square tiles about 23 cm on a side)
25-ml graduated cylinder, 1
Medicine dropper, 1
Isopropyl alcohol, 70% (rubbing alcohol), 1 bottle

Activity 1 — Testing a Hypothesis

If you drop a pencil on a tile floor, sometimes it will come to rest on a crack. Here is a hypothesis about dropping pencils:

> If a pencil is dropped on a tile floor many times, half the time it will come to rest on a crack.

Construct an experiment to test this hypothesis. Refer to *Objective 1* for the various factors you should consider in constructing and carrying out your experiment. After you have completed your experiment and written a report, refer to the *Comments on Activities* at the end of this exercise.

Activity 2 — Constructing a Question

A strip of plastic tape was put around a medicine dropper, and the dropper was filled with water up to the bottom edge of the tape. The water was then expelled from the dropper, drop by drop, and the drops were counted. Next, the dropper was rinsed by filling it once with a mixture of 10 milliliters of water and 10 milliliters of 70% isopropyl alcohol. It was then filled to the bottom of the tape with the water-alcohol mixture. Then, the mixture was expelled drop by drop. The observations were as follows.

Water	14 drops
Water-alcohol mixture (50:50)	38 drops

Construct a question suggested by these data and design and conduct an experiment to answer your question. Refer to

Objective 2 before you start. When you have completed your experiment and written a report of it, refer to the *Comments on Activities.*

COMMENTS ON ACTIVITIES

ACTIVITY 1

What variables did you control or measure? Among those you may have considered are:

What kind of pencil did you drop?
How long was the pencil?
Was the pencil sharpened?
Did the pencil have an eraser?
What was the height from which the pencil was dropped?
Was the pencil always dropped from the same place?
Did you hold the pencil in same position each time you dropped it?
How many times was the pencil dropped?
How large were the floor tiles?
What was the shape of the tiles?
How wide were the cracks?

Did you construct any operational definitions? What does the phrase, "come to rest on a crack," mean? If the tip of the pencil came to rest just touching a crack, did you count it as "on" or "not on"? Finally, did you state whether or not the hypothesis was supported by your data?

Here is a report of an experiment similar to the one you may have done.

> A sharpened wooden pencil with a rubber eraser was dropped on a tile floor from the height of 75 centimeters. The pencil was 14.5 centimeters long. The tiles were square and made of linoleum. Each side of a tile measured 23 centimeters. The joints between the tiles were too narrow to measure. The pencil was held to a horizontal position before being dropped. A trial was not counted if the pencil just touched a crack. The pencil was dropped 100 times, each time from a different orientation. In 50 cases, the pencil came to rest on a crack. The data support the hypothesis.
>
> The experiment was repeated, but this time the pencil was dropped from the same orientation each time. The orientation with respect to the floor tiles is shown in Figure 1. Again, the pencil was dropped 100 times. This time, the pencil came to rest on a crack 46 times. These data do not support the hypothesis quite as well as the first set.

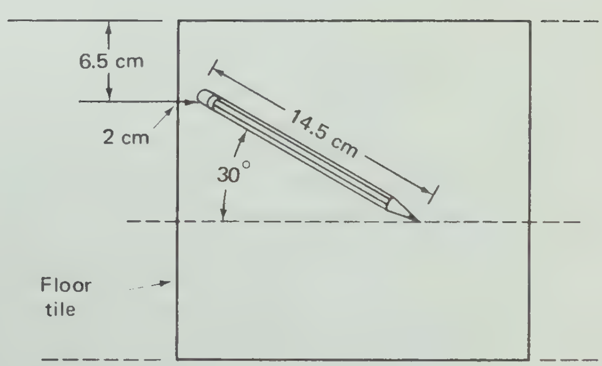

FIGURE 1

The length of the pencil obviously will affect the results

if the pencil is long relative to the square. If is is longer than a diagonal of the square, it must come to rest on a crack every time. To test whether a short pencil will fall on a crack 50% of the trials, a pencil 7 centimeters long was dropped 100 times, and it came to rest on a crack only 34 times. These data do not support the hypothesis. The hypothesis might be restated as follows.

If a pencil is dropped on a tile floor many times, the number of times it falls on a crack depends on how long it is. The shorter it is relative to the size of the tiles, the fewer times it will come to rest on a crack.

There are still, of course, other variables that you might have tested, such as height from which pencil was dropped, whether it was dropped from a vertical position, and so on.

ACTIVITY 2

There are, of course, many questions that you might have raised. Here is one as an example. Is there a linear relationship between the number of drops and the composition of the water-alcohol mixture? To answer this question, water-alcohol mixtures of various compositions should be tested. Variables such as temperature of the liquids, volume of liquid tested, position in which the medicine dropper is held, and so on, should be held constant.

The data from one experiment are shown in Figure 2. It is clear that the relationship between the number of drops and the composition (by volume) of the water-alcohol mixture is not linear.

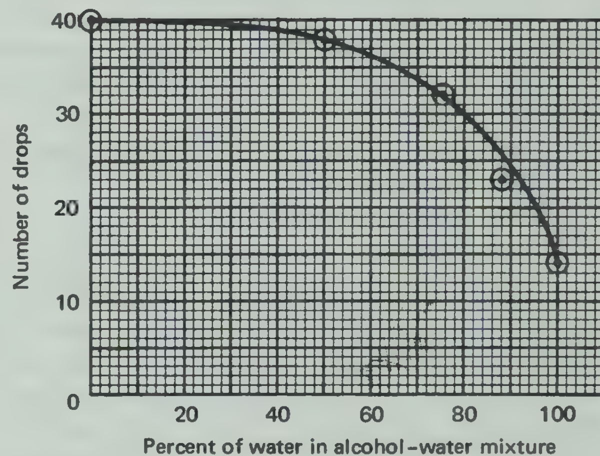

FIGURE 2

PART 4: OVERVIEW OF CONCEPTS

The primary objective of *Science—A Process Approach* is that the child acquire competence in the processes of science. Children develop this competence as they use the processes in science experiences, and as they behave as scientists, they learn science. This section reviews briefly the variety of science content of the program under the headings: physical sciences, biological sciences, and mathematics. The letters in parentheses indicate the Part in which an experience is encountered.

PHYSICAL SCIENCES

The physical science content is drawn from physics, chemistry, and earth sciences. Because simple physical systems are relatively easy to investigate, there is more physics than chemistry content in the early Parts. Chemistry and earth science content is found mainly in the last three Parts.

Solids and Liquids and Their Properties

Pupils use all of their senses to observe and distinguish between various solid objects and liquids. Properties that can be observed directly are introduced first. The pupils observe color, shape, size, texture, odor, and taste (cautiously—when the teacher tells them they may) in identifying, describing, and classifying objects (A). The properties of luster and hardness are introduced later (E) and are used together with other properties, such as color, in identifying minerals.

The pupils further investigate the property of color when they construct a color wheel (C) and when they use a grating spectroscope (G) to observe the spectrum of white light and of light that is transmitted by filters of different colors.

One property that distinguishes solids and liquids from gases is called *compressibility*. The pupils investigate compressibility of solids and liquids at two levels. First (C), they put solids, such as sand or paper clips, and water into balloons and try to compress them in a cylinder fitted with a piston. At the higher level (F), they put water and other liquids into a graduated syringe and try to measure their compressibility by increasing the force on the plunger.

Magnetic properties of certain solids are introduced (B) to give the children an opportunity to observe a property that is not immediately obvious. Two bars may look alike, but to find the one that is a magnet the pupil must test both bars with paper clips, iron nails, or other iron objects. He learns that some objects are attracted by a magnet while others are not. Later (D), he observes the magnetic field around a magnet as it is revealed in a pattern of iron filings. In the

same exercise, the child identifies the north-seeking and south-seeking poles of a magnet. He also learns to construct an electromagnet and compares its properties to those of a permanent magnet. Later (F), the children map the magnetic field around a magnet by constructing compass-direction lines. Interpreting these in relation to the geographic orientation of the magnet on the earth's surface, they discover that the earth itself behaves like a large magnet.

After working with properties such as physical state and magnetism, the child is ready to work with properties such as density (G). Density is calculated from measurements of two properties—mass and volume. The pupils determine density both graphically (by plotting the masses and volumes of objects) and arithmetically (by dividing the mass by the volume). Some children may independently discover Archimedes' principle in this exercise.

The pupils compare the viscosities of various liquids in two ways (G): by the rates at which similar objects fall through columns of the liquids and by the rates at which liquids flow through an orifice. In this exercise, the pupils investigate the effect of temperature on viscosity and experiment to determine whether or not there is a simple relationship between the densities and the viscosities of liquids.

In another exercise (D), the pupils investigate the effect of the size of an object on the rate at which it falls through water. They shake up a mixture of clay, sand, pebbles, and water, and note that the solids settle out with the pebbles mainly on the bottom, the sand in the middle, and the clay on top.

The most sophisticated property of solids considered in *Science—A Process Approach* is semipermeability (G). Children investigate various plastic membranes and measure qualitatively or semi-quantitatively whether various substances in aqueous solution will pass through them.

Gases and Their Properties

As one might expect, children have more difficulty with the idea of gases than with the concept of solids and liquids. There are probably two main reasons for this. First, there are not many gases that can be seen; second, most primary grade children think *gas* means gasoline. Gases are introduced early (B) and are used in ten exercises in the following five Parts. The pupils balance an inflated and an uninflated balloon and learn that air has mass (B). Later (C), they put an inflated balloon into a cylinder fitted with a plunger and observe the decrease in size of the balloon as air is forced into the cylinder. The compressibility of air and also carbon dioxide is investigated quantitatively (G) by measuring the volume of gas in a graduated syringe as increasing force is applied to the plunger. In this same exercise, the pupils investigate the effect of reducing the force on the plunger of a syringe partly filled with air, with the plunger down, by placing weights on a pan fastened to the plunger. With this apparatus, the pupils make a rough measurement of atmospheric pressure and come surprisingly close to the proper value of about 10 newtons per square centimeter.

The pupils collect and test for carbon dioxide and oxygen (G). They learn that carbon dioxide is a gas that turns limewater milky and that turns bromthymol blue solution from green to yellow; they learn that oxygen is a gas that makes a glowing splint burst into flame. Armed with these operational definitions, they test the gases produced by *Elodea* in light, by seltzer tablets in water, by hydrogen peroxide and manganese dioxide, by germinating seeds, by yeast fermenting sugar, and by a carbonated drink.

Changes in Properties

Describing properties that change is a more difficult task for children than describing static properties. It is partly for this reason that chemistry content is used more in the latter Parts of *Science—A Process Approach.* Chemical properties of substances are observed only when their

properties change. The first exercise involving change in properties requires children to observe and describe color changes (A), such as the change in color of pieces of cloth dyed with Congo red dye as the pieces are dipped into a solution of citric acid or sodium bicarbonate. A follow-up to this exercise is one with content from the biological sciences, observing color changes in plants (B).

In other exercises, children observe and describe solids changing to liquids (A). In an investigation of the rate at which water evaporates from different kinds of cloth, they are introduced to the fact that liquids evaporate (D). They determine the rate of evaporation by weighing each piece of cloth at intervals, and they investigate the effects of temperature and air movement on evaporation rate.

Several exercises with content from the earth sciences involve change. Children observe and record wind velocity, cloud cover, air temperature, and other aspects of the weather (B) and describe the changes in these characteristics from day to day. They construct a simple sundial (C) and observe changes in the direction and length of a shadow during the day. Later (F), they make similar observations of the shortest shadow. Combining this information with their investigation of the magnetic field of the earth, they identify and define magnetic declination.

The pupils investigate chemical reactions (E) as a means of identifying materials. They work with four white powders (baking soda, baking powder, corn starch, and talc) and three liquids (water, vinegar, and dilute iodine solution). They prepare liquid-solid pairs in all the possible combinations, observe any changes that occur, and record their data on punch cards. The recorded information is then used to identify an unknown powder which is one of the powders they have investigated previously. In another exercise on chemical change (F), the pupils study the variables that affect the development of the color of blueprint and Ozalid papers. In that same Part (F), they measure the time required for seltzer tablets to dissolve in water of different temperatures. They plot their data on a graph and learn that as temperature increases reaction time decreases, but that the relationship is not linear.

Rate of change of volume of an enclosed gas is used as a measure of the rate at which steel wool rusts under various conditions (G). The pupils learn that as steel wool rusts something disappears from the air. A related exercise is an investigation of the burning time of a candle covered by a glass jar (D). In that exercise, the children do not measure the change in volume of gas. Instead, they measure the burning time under jars of different volumes and find that the larger the jar the longer the candle burns. The jars must, of course, be approximately the same shape.

Temperature and Heat

Pupils are introduced to temperature with comparative adjectives such as *warmer* and *cooler* (A). They order containers of water first by feeling them and then by using a color-coded thermometer. Next (B), they use a thermometer with a numbered scale and later (C), one with a numbered scale which includes negative numbers. The child is already familiar with the fact that an incandescent light gives off white light and that an electric toaster wire glows red. He learns (C) that the color of a glowing object can be used as a measure of the temperature of the object.

The term *heat* is first used in an exercise (E) in which the children compare the rates at which rods of different materials conduct heat from the flame of an alcohol lamp. The concept of heat is developed further and a technique for measuring heat is learned in an exercise (G) in which the pupils heat different (measured) volumes of water over similar candles. They learn that the calorie is the unit in which heat is measured. At the end of this exercise, they measure the rate at which heat is transferred from an immersion heater to a measured volume of water. A little later

in the same year, the pupils use their knowledge of how to measure heat in an exercise (G) in which they measure roughly the amount of heat that is produced in a film cassette filled with water as the cassette is rubbed back and forth many times between two meter sticks fastened together with stout rubber bands.

Force and Motion

The science content of almost one-tenth o, the exercises in *Science—A Process Approach* involves force and motion. The first exercise (A) in the group emphasizes motion such as a fish swimming or a flag blowing in the wind; it also discusses direction of motion. Next, the children roll a ball down an inclined plane arranged so that the ball strikes a box at the bottom of the plane. By using balls of different weights, they learn that the heavier the ball is, the farther the box will move.

The children become acquainted with the concept of speed in an exercise (D) in which they use a stopwatch and metric tape to measure the speed at which various objects move. The idea of speed is used in several later exercises. In one of these (D), they are introduced to the notion of relative motion as they first describe the motion of a block in a wagon that is being pulled past them. Then they describe the lack of motion, relative to themselves, as they sit in the moving wagon, holding the block.

Circular motion is introduced in an exercise (D) in which the pupils describe the motion of an object placed in different positions on a phonograph turntable. Later (E), they measure the linear speed of different size wheels rotating at the same speed and learn that the larger wheels roll farther than the smaller ones in the same amount of time. They learn that the ratio of the circumference to the diameter of a circle is always the same, about 3.1, and use this knowledge to predict how far a wheel will roll when it makes one or several rotations.

The pupils use an equal-arm balance for the first time (B) and learn that it is in balance when the earth-pull on the two pans is equal; here they begin to become familiar with the concept of *force.* Later (C), the pupils use springs and a color-strip scale to measure not only earth-pull, but also the force required to move a box across the floor.

They use vectors to represent forces in Part D, using arrows to show direction and magnitude. They also learn that if all the forces acting on a movable object are balanced, the object will not move; if one of the forces is removed, the forces are unbalanced and the object will move.

By attaching a rubber band to a four wheel cart, stretching the band and letting the cart go, the pupil learns that the farther the band is stretched the farther the cart will roll before it stops (E). In this exercise, the pupil learns to use the term *acceleration* to describe change in speed—either speeding up or slowing down. Pupils' abilities to use vectors are reinforced in this exercise. In the following exercise (E), *the newton* is introduced as the unit of force. Throughout the remaining parts of the program the pupils are expected to be able to measure and describe the magnitudes of forces in newtons. Forces are considered in several other exercises. For example, in Part F the pupils learn the law of the lever.

The terms *inertia* and *mass* are introduced in Part F, but in previous exercises the pupils investigate phenomena which lay the groundwork for a discussion of those terms. In one of these exercises (E), the pupil is given several cylinders all of the same diameter but of different lengths. Some of the cylinders are solid and some are hollow. Some are made of steel, some of aluminum, and some of plastic. The pupil rolls pairs of cylinders down an inclined plane and tries to determine what variable or variables account for the fact that some cylinders roll faster than others. He tries mass, length, and material from which the cylinder is made and finally reaches the conclusion that all of the solid cylinders roll faster than the hollow ones.

The idea of inertia becomes explicit in the exercise in which mass is introduced as the measure of inertia (F). In that exercise, the pupils use rubber bands to accelerate carts with different loads and a vibrator to compare the masses of various small objects.

Miscellaneous Topics

In several exercises, the pupils investigate electric circuits. First (E), they use a simple dry-cell-and-bulb circuit to test the hidden connections of terminals on circuit boards. Next (E), they learn to identify and construct series and parallel circuits using several bulbs and dry cells. The pupils use a simple circuit to test a variety of substances to determine whether they will conduct electricity (E). In this exercise, they also test the hypothesis that good conductors of heat are also good conductors of electricity.

The pupils do some work with light and optics in the last three Parts of *Science—A Process Approach.* They reflect beams of light with mirrors and learn that the angle of reflection is equal to the angle of incidence (E). They use lenses and pin-hole cameras and investigate the relationship of the sizes of the object and the image and the distances of the object and image from the lens or pin hole (F).

BIOLOGICAL SCIENCES

Biological concepts form the bases of exercises throughout the entire span of *Science—A Process Approach.* The exercises are intertwined with those that describe and measure the physical universe, thus satisfying in major degree the specification that the child learn as much as he can about the interaction between living things and their environment.

Observing and Describing Living Things

In their earliest school experiences, children are introduced to living things and things that have been living. The children learn to identify similarities and differences of living things and those that have been living. Using these similarities and differences, they classify them. Then, using these classification schemes a child describes one object so that another child can readily identify it. These abilities provide a solid basis for later and more detailed study of interactions of living things with their environment. In *Science—A Process Approach* (A,B), children become acquainted with a multitude of living things such as leaves, nuts, shells, animals, and plants in an aquarium, and animals and plants in their natural environment. They begin to see what distinguishes living from nonliving objects around them. Living things eat, grow, reproduce, and move about freely. The children describe their color, their size, their shape, their symmetry or lack of it, their odor, and their locomotion. Soon they are able to describe color changes that occur in plant leaves and the movement of a potted plant in response to sunlight or the response of a sensitive plant to touch or heat (B).

Modes of Living and Behavior of Animals

Soon after, the child starts his investigation of modes of living and behavior of animals. He is ready to study how animals walk, run, or fly and can investigate for himself their responses to stimuli. He studies living things in an aquarium (C) in greater depth than he did earlier (B); he walks through the woods observing animal tracks and traces, inferring the existence and function of claws and beaks, and inferring the strengths of other animal parts as, for example, legs for digging (D). The children begin their study of life cycles early (C) and then meet other examples as their study of animals is continued in later grades. Use of living animals rather than

pictures is emphasized, and field trips for collection of species are recommended. Young children like to hear and read about dinosaurs. This interest is used as a basis for study of scale drawings in pictures and maps (C).

Because children enjoy having live animals in the classroom and can learn a great deal about their development and behavior from day to day observations, several exercises are included to guide investigation of specific phenomena. Two of these are *Guinea Pigs in a Maze* (E) and *Nutrition of a Small Warm-Blooded Animal* (F). The guinea pigs are kept in the classroom two weeks or so before the children place them in a maze they have constructed. The children record running time in the maze over several trials. They then compare changes in learning time in several trials of two or more guinea pigs. The nutrition exercise provides for a number of variations in the study of warm-blooded animals including the study of reproduction of gerbils and perhaps an introduction to population problems. A further illustration of the rapid multiplication of populations is provided by the study of imaginary animals called *glurks* (F). Glurks are small animals that separate into two parts, each a new glurk, at the end of each day.

The children study the responses of brine shrimp hatched in the classroom to changes in environmental factors (F). Will brine shrimp hatch in fresh water? Will they hatch faster in warm water than in cold water? Can brine shrimp live if given sugar for food instead of yeast? What is the effect of crowding on young shrimp? These and other questions lead to hypotheses the children test.

An introduction to genetics is provided in two exercises. One is concerned with tasters and nontasters using PTC papers (F). An experiment with reproduction of two generations of drosophila (G) enables the children to study the passing on of dominant and recessive characteristics through two generations.

Human Behavior and Physiology

While children recognize that humans are part of the family of animals, this content review treats human studies separately from animal studies. In the human category, there are a number of studies that ordinarily are classified as belonging to the social rather than the biological sciences.

First, the children learn to use all of their senses in making accurate observations. They see, listen, smell, taste (with caution), and examine a variety of objects for texture (smooth or rough) for weight, for hardness, for the presence of warmth, and for furriness. They experience what they can do with their bodies through their senses.

Later, when their interest in themselves and their bodies has increased, they are ready to investigate such body functions as the path by which stimuli pass through their central nervous system to produce responses (F), whether they are tasters or nontasters of PTC paper (F), and the variations in their perceptual judgment in viewing optical illusions (G). They count their own and their classmates' pulsebeats, as a doctor does. They also count the number of times they inhale (or exhale) in a minute, and measure the volume of the air they exhale, using a polyethylene tube to collect the air exhaled (F). Simple charts are provided for them in tracing a stimulus to the eye that may result in a response with hand or foot. That some can taste PTC paper and others not taste it (with little middle ground) comes as a revelation to them. Some parts of their experimenting with their own perceptual judgment may also be a surprise when they discover what factors may modify this judgment. They also find out about how they learn and why forgetting takes place; they investigate their reaction time to light, sound, or touch (F), and the resolving power of the eye (G). They learn codes for sending messages in order to study how interference may affect learning (G). For example, if a new code is to be learned after they already know one, what characteristics of the two codes will interfere with their new learning?

In the tryout classes, children often had great enthusiasm for these psychological topics that have rarely been introduced in elementary schools. Although an immediate reaction was often that these topics are "not science," the application of their competence in the processes of science soon convinced the children that the methods of the natural sciences are equally useful in social studies, which then become social sciences.

Microbiology

In *Science—A Process Approach* the child may first use a microscope in examining the surface of a leaf (D). He sees small openings (stomates) through which water can pass in transpiration. Then he becomes more proficient in the use of the microscope in the study of living cells (E) and in measuring small things by comparing them with the size of the field of the microscope (F).

He examines both living things (algae, elodea, insect wings, tissues of vegetables, yeast) and nonliving things (cork, grains of salt, sugar or sand) under the microscope, constructs drawings of what he sees, and makes comparisons of cell structures. The children also examine more carefully the growth of mold colonies in investigation of factors in the environment that affect mold growth (E). Much earlier (B), they examine mold gardens and describe their appearance and growth changes. Finally (G), they meet living things that produce carbon dioxide in the process of fermentation—again investigating environmental factors that affect the rate of fermentation.

Seeds, Seed Germination, and Plant Growth

Most elementary school children have enjoyed the experience of planting seeds in the spring and watching them grow. In *Science—A Process Approach,* the children have this experience in each of at least three years in a new investigation each time. They see and measure how some seeds expand by soaking up water before planting (B). They cut open the seeds and examine the embryo plant with some care. They observe the growth of roots, stems and leaves of seedlings at regular intervals, watching the changes in a grid or series of markings they have put on the plant part (D).

Some of the other phenomena related to plant growth and development that the children investigate are growth from parts of plants (bulbs, leaves, or a section of a potato) (C), environmental factors affecting orientation of growth, such as sunlight and gravity (F), and how plants grow in various colors of light (G) and with different soil nutrients (G). They test for the presence of starch in the growing plants as they are introduced to photosynthesis.

The pupils investigate the transpiration of water from plants by measuring the amount of water used each hour by a plant during different parts of the day, and they predict the amount of water that will be used during other hours in other parts of the day. By wrapping the plants in a polyethylene bag, they find that moisture is lost from the leaves and stems. Then, they measure the amount of water lost (D). In Part E, they study the loss of moisture from potatoes by evaporation. Parts of plants (cotyledon, stem, leaf, petiole) are identified by operational definitions so that these terms become a part of the children's vocabulary (F). When they are studying sections of cut things, the children observe the growth rings in trees or pieces of wood and learn to determine whether a cut of a plant part is a transverse, longitudinal, or slant section (E), a skill that will become more useful as slides of plant sections are examined for cell structure in later study of biology.

MATHEMATICAL TOPICS

So that *Science—A Process Approach* will accurately reflect the spirit of modern science, the science experiences of the children are often quantitative. Traditional elementary school science has been almost exclusively descriptive. Important descriptive science concepts are not neglected

here. They are strengthened by making them also quantitative. In *Science—A Process Approach,* science and mathematics are deliberately impossible to separate. The mathematical topics reviewed here comprise an important part of science—certainly graphs, measurement, and much of informal geometry are science topics. One day the distinction between science and mathematics in elementary school will no longer be recognized!

Five of the processes of science include many of the skills that should be developed in a school's mathematics program—*Using Numbers, Using Space/Time Relationships, Communicating* (with tables and graphs), *Measuring,* and *Interpreting Data.* These skills, needed for the study of quantitative science, are not taught in all elementary mathematics programs, and if they are included it is often after the time that the children need to use them in this program. The three topics for which supplementary work in science classes becomes most necessary are graphing, division, and decimals.

Numbers and Number Notation

First children learn about sets and their members, order properties of whole numbers, counting, and numerals (A). They are then introduced to the number line, including the negative integers $^{-}1$, $^{-}2$, $^{-}3$, ... $^{-}9$ (B). The number line is also used to introduce addition of positive integers less than 10. A little later they add positive and negative integers between $^{-}10$ and 10 (B and C). An exercise in multiplication of positive integers less than 10 is provided for the purpose of enabling the children to divide in order to find rates (an exceedingly important topic in science) and means (D). Until the children need to divide, the work in numbers is not too far ahead of the treatment of these topics in a modern mathematics program.

The metric system of measurement is used from the first introduction of a standard unit of length (B). Later, the children use decimal notation to record tenths of a unit (D, E). Using the number line, decimal notation for tenths can be introduced and used before the children have acquired skills with common fractions. Most elementary school science experiences can be adequately taken care of by using decimals correct to the nearest tenth, at least until grades 5 and 6. Children are introduced to scientific notation for whole numbers more because of a need for knowledge about this notation in outside reading than for the science class (E, F).

Measurement

Children first learn to measure by using arbitrary units. Later, standard metric units are introduced and used. This procedure is followed in measuring lengths (B), temperature (B, C), weight, forces, and mass (B, C, F), and angles (E). Early in their experience they learn to compare areas and volumes using arbitrary units (B). Metric measures of volume in milliliters becomes a useful skill (C). Their attention is first called to comparisons of time intervals (A, B). Later, they learn to read time on the clock to the nearest minute (B) and to use a stopwatch to record intervals to the nearest tenth of a second (E). As a part of the study of measuring, the children learn not only to measure carefully, but they also acquire experience in estimating lengths, volumes, time, weight, and mass. They measure angles in order to specify direction (B). They learn about angles of incidence and reflection (E), and they study angular velocity (E). In measuring, they learn how scientists use the terms *precision* and *accuracy* (E). They also measure small things using a microscope (F).

Graphing

Scientists in all fields use graphs as one of their principal means of communication. Inferences, predictions, and hypotheses are often derived from graphs. A scientist uses graphs to point a

direction for new experiments and new generalizations as well as to record and report what he has already found out. The children first construct bar graphs (B, C). The rectangular coordinate system is then introduced (C) and used throughout the remainder of the program. Three-dimensional coordinates are utilized in relation to describing position on contour maps (F). In the intermediate grades, the interpretation of data recorded in tables and graphs is an essential skill in experimenting.

The children learn to interpolate and extrapolate from graphs (C) and use these skills frequently thereafter. Their study of scales in pictures, maps, and charts is related to their work in choosing scales for coordinate axes (C, D). Two applications of graphs that provide experience with other mathematical concepts are the construction of graphs of data collected in a survey of opinion (C) and graphs of data obtained in determining a relationship between the distance of a viewer from an object and his field of vision (E).

Probability

There is one exercise on probability (F) which builds on the exercise that immediately precedes it in which the children study the human characteristics of being a taster or a nontaster. Later, in a supplementary exercise (G), the children explore probability further as they experiment with generations of drosophila with different characteristics. Probability has an exceedingly important place in modern science. Even though many scientific uses of probability are not appropriate for elementary school science, probability itself is so important to science and so appealing to children (and so often neglected in elementary school mathematics) that it deserves a place in modern elementary school science.

Other Geometric Topics

In acquiring competence in *Using Space/Time Relationships,* young children identify and name both plane and three-dimensional shapes (A). They use this skill in communicating about objects and phenomena in a variety of scientific experiences. Included in this study is symmetry with respect to a line and a plane (B). The pupils also become accurate in the use of the terms *straight* and *curved lines,* and *plane* and *curved surfaces* (C). They learn, for example, that straight lines can be drawn on some surfaces and not on others and about great circles on a sphere. An important skill for them in later scientific work is the ability to see the relationships between two-dimensional and three-dimensional figures, such as the rectangular faces of a rectangular prism (A), the plane-figure shadows of three-dimensional objects (D), and the plane sections of three-dimensional objects (E). They learn to construct plane representations of three-dimensional figures (E) and to identify three-dimensional objects from their shadows or plane sections.

PART 5: SCIENCE BACKGROUND PAPERS

THE METRIC SYSTEM

The Romans defined the mile as 1000 paces. The word *mile* is derived from the Latin word *mille* meaning 1000. The Roman pace was two steps and was equal to five Roman feet. This was an approach to a decimal system of measurement of length, but the system did not last. The British, for example, defined the mile as 5,280 feet or eight furlongs. Certainly not a decimal system.

Since 10 is the base of our number system, the value of a measuring system also based on 10 is obvious. Calculating with such measurements is much simpler than calculating with measurement not based on 10, for example, inches, feet, and yards. Although there were some ancient decimal measuring systems, it was not until the latter part of the eighteenth century that the decimal system that is now widely used throughout the world was adopted. This system, called the *metric system,* was adopted first in France in the 1790's and soon spread to other countries. The United States considered adopting it when a decimal money system was adopted. Thomas Jefferson favored its adoption. He also favored defining the *meter* (the unit of length in the metric system), as the length of a pendulum that would swing once in a second.

The meter was defined by the scientists who developed the system at the Paris Academy of Sciences as one ten-millionth of the distance from the equator to the north pole along the longitude of Paris. This distance had been measured with great care earlier in the century. For the first time, a measuring unit was related to a fixed physical measure. More recently, the meter has been redefined in terms of the wavelength of the light that produces one of the lines in the spectrum of an isotope of the element called *krypton.*

The unit of mass in the metric system is also related to a fixed physical measure. The unit is the *gram,* and is the mass of one cubic centimeter of water at its greatest density (4°C).

The names of the metric units that are used in *Science—A Process Approach,* their abbreviations, and their equivalents in the United States system, are listed in Figure 1.

The metric system is used throughout the world by scientists and in most of the countries of the non-English-speaking world. English-speaking countries are gradually accepting the metric system. England, for example, has converted to decimal currency, and is preparing to adopt the metric system. It has been legal to use the metric system in the United States for over 100 years. Indeed, the United States units of measure have been defined in terms of metric units since late in the nineteenth century.

Measure	Metric Unit	Abbreviation	Equivalent in U.S. measure
Length	Meter	m	39.37 inches
Volume	Liter (cubic decimeter)	(l) (dm^3)	1.06 quarts
Mass	Gram	g	0.035 ounce
Weight or Force	Newton	N	0.224 pounds
Temperature	Degree Celsius	°C	1.8 degrees Fahrenheit
Heat	Calorie	cal	0.004 British Thermal Unit (BTU)

FIGURE 1

MEASURING LENGTH

Examine the number line, shown in Figure 2. That number line is part of a metric scale. Ten such scales laid end to end would be equal to one meter. If you have a meterstick, examine it; if not, use the scale in Figure 2 or a 30-centimeter ruler to mark off a length of one meter on your desk top. The scale in Figure 2 is one tenth of a meter and is called one *decimeter.* The decimeter scale is divided into ten smaller

FIGURE 2

lengths. How many of those smaller lengths are there in a meter? (One hundred.) So each of those smaller lengths is one hundredth of a meter and is called a *centimeter.* The scale in Figure 2 shows each centimeter divided, in turn, into ten smaller parts. How many of those smallest divisions would there be in a meter? (One thousand.) Each of the smallest divisions on the scale, therefore, is one thousandth of a meter and is called a *millimeter.*

The Latin prefixes *deci-, centi-,* and *milli-* are used to name tenths, hundredths, and thousandths of a metric unit. These are the only prefixes for decimal parts of units that are used in *Science—A Process Approach*. However, you may be interested in seeing some other prefixes that are used by scientists. They are listed in Figure 3 along with the Greek prefixes that are used for multiples of a metric unit.

What would you call 1000 meters? (A kilometer.) *Kilo-* is the only prefix for multiples of metric units used in this program.

Prefixes for decimal parts of a metric unit	Prefixes for multiples of a metric unit
10^{-1}* deci-	10 deca-
10^{-2} centi-	10^{2} hecto-
10^{-3} milli-	10^{3} kilo-
10^{-6} micro-	10^{6} mega -
10^{-9} nano-	10^{9} giga-
10^{-12} pico-	10^{12} tera-

FIGURE 3

MEASURING AREA AND VOLUME

The metric units of length are also used to state areas and volumes. For example, the area of a room might be expressed in square meters (m^2). The volume of sand in a container would be expressed in cubic centimeters (cm^3). There is a special unit for measuring the volume of liquids. It is the *liter.* Actually, the liter has recently been dropped as an official name for a unit in the metric system, but it will undoubtedly continue to be used unofficially for a long time. A liter is the same as one cubic decimeter. Figure 4 is a drawing of one cubic decimeter.

How many cubic centimeters are there in one cubic decimeter? (One thousand.) A cubic centimeter is one thousandth of a cubic decimeter. We have said that a cubic decimeter of liquid is also called a liter. What other name might we use for one cubic centimeter, or one thousandth of a liter, of a liquid? (One milliliter.) In *Science—A Process Approach,* the terms liter (l) and milliliter (ml) are used in preference to cubic decimeter (dm^3) and cubic centimeter (cm^3).

Liquids are measured in various types of containers. A common type for scientific work is a *graduated cylinder.* Figure 5 shows a typical graduated cylinder, of one-liter capacity and with graduation marks every 100 milliliters. Other common types are a 100-milliliter cylinder with graduation marks at every milliliter, and a 10-milliliter cylinder with marks for every 0.2 milliliter.

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*If you are not familiar with this method of writing decimal parts and multiples of units, read the background paper, *Scientific Notation.*

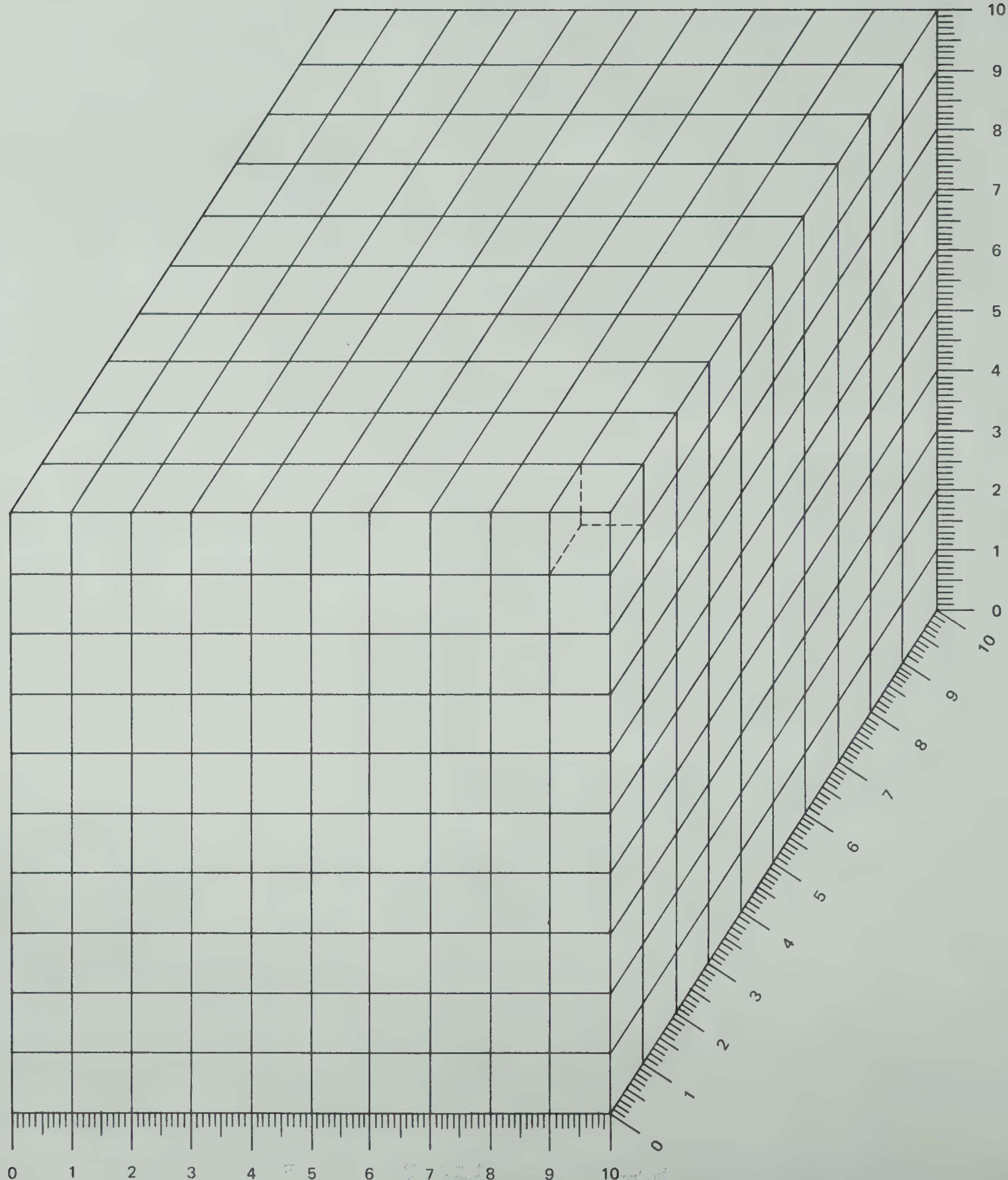

FIGURE 4

MEASURING MASS

We have said that the unit of mass in the metric system is the gram, which is defined as the mass of one cubic centimeter (one milliliter) of water at 4°C. It is helpful to know this, because it enables you to make your own standard masses if you do not have metric masses available. Let's see how this can be done, using water as the standard for calibrating them. You do not need to be concerned if you use water at room temperature (25°C) instead of 4°C, since one milliliter of water at 25° has a mass only 0.3 percent less than one gram.

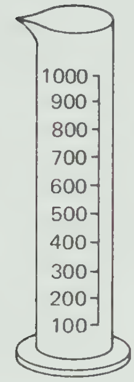

FIGURE 5

Suppose that you have two identical containers, each of which will hold one liter of water. The empty containers should have the same mass. Suppose you also have available an equal-arm balance and some large paper clips. Now, you put one liter of water in one container and place it on the left pan of the balance. You put the empty container on the right pan. You observe that the balance is now unbalanced. You begin to add paper clips, one by one, to the empty container on the right pan. Finally, suppose that just as you put the thousandth paper clip into the container the pans become balanced again. The container and one liter of water on the left pan are balanced by the container and 1,000 paper clips on the right pan. (See Figure 6.)

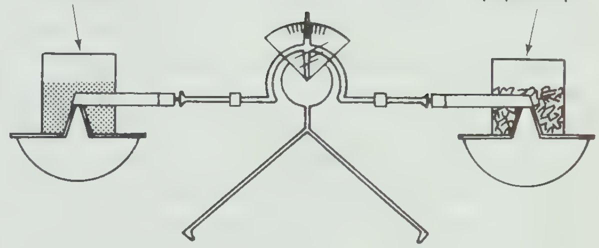

FIGURE 6

Because the two containers balanced each other when they were empty, the 1,000 large paper clips must be balancing the one liter of water. The mass of the 1,000 paper clips is called a kilogram because it balances the mass of one liter (one kilogram) of water. So each large paper clip has the mass of one thousandth of a kilogram, or one gram. Of course, it is not likely that you will find paper clips with a mass exactly one gram, but you can use this procedure to determine the mass of one paper clip. If 80 paper clips exactly balance 100 milliliters of water, what would be the mass of one paper clip? ($100 \div 80 = 1.25$. Each paper clip has a mass of 1.25 g.) Once you have calibrated paper clips or other uniform solid objects this way, you can use them as standard units for measuring the mass of other objects.

OTHER METRIC UNITS

Three other metric units are used in *Science—A Process Approach*, one for measuring temperature, one for measuring heat, and the other for measuring force. The units for measuring temperature (the *degree Celsius*) and heat (the *calorie*) will be discussed in the following paper, *Temperature and Heat.* The unit of force is the *newton* (N). The newton can be defined as the gravitational force at sea level on an object having a mass of 102 grams. Since gravitational force decreases with distance from the center of the earth, but mass

does not, the force on a mass of 102 grams is less than a newton at altitudes above sea level.* Other factors also influence the apparent gravitational force, but all the effects are quite small. For example, the gravitational force is only 0.05 percent less in Denver, Colorado, than in Washington, D.C., and 0.5 percent less at the equator than at the poles. Therefore, we are not far wrong if we say that a 102 gram mass anywhere on earth will give a force of one newton.

Forces can be measured with a spring scale, a device with which it is possible to read from a scale the amount of force being exerted on a spring by an object suspended from it. The spring scale used in ***Science—A Process Approach*** is shown in Figure 7. A spring is suspended at the top from a hook mounted under a tripod. The spring passes through a transparent cylinder marked with a graduated scale. A pan, in which objects may be placed, is suspended from the bottom of the spring. When the pan is empty, the bottom of the spring is at the zero point on the scale. You can calibrate any such spring scale in newtons by adding multiples of 102-gram masses successively from the pan and marking the corresponding extensions of the spring on the scale to represent 1, 2, 3, and so on, newtons. The spring scale you then have will measure forces in newtons regardless of the direction in which the force is being exerted. You can use such a scale, for example, to measure the force required to pull a book across a desk top, as well as to measure the force down exerted by a handful of marbles.

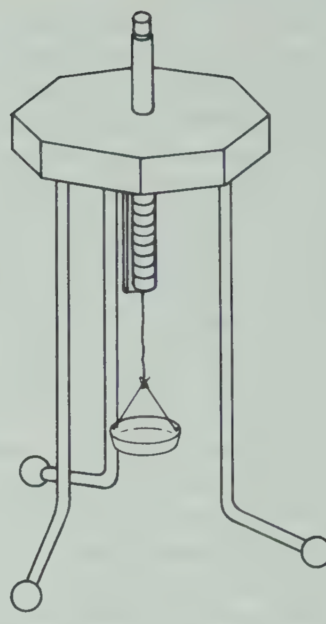

FIGURE 7

The calibrations of standardized springs are usually expressed in terms of the unit of force required to stretch the spring one centimeter. A calibrated spring with a constant of one newton per centimeter, for example, will stretch one centimeter for every newton force applied to it; a calibrated spring with a constant of 0.5 newton per centimeter will stretch one centimeter for every 0.5 newton force applied to it. Although standardized springs of various calibrations are available, we recommend that you calibrate your own spring scales.

If the metric system is new or unfamiliar to you, you will soon find that the convenience of manipulating standard decimal units of measurement outweighs the initial inconvenience of learning the new units. For your pupils, early development of skill in the use of the metric system units will save them countless days of calculating, in terms of school time. We urge you to insist on the use of metric units in as many contexts of everyday experience as possible.

*See also the background paper, *Mass,* on page 209.

MEASURING TEMPERATURE AND HEAT

At the time that the Paris Academy of Sciences developed the metric system, in the latter part of the eighteenth century they adopted a scale for measuring temperature that had been invented in Sweden earlier in the century. The inventor was Anders Celsius, an astronomer. This scale, for many years called the centigrade scale, is now called the Celsius scale.

CALIBRATING A THERMOMETER

If you would like to calibrate a thermometer to measure temperatures on the Celsius scale, you will need an uncalibrated thermometer tube. You might use a thermometer from one of the kits of *Science—A Process Approach*. Simply remove the thermometer tube from its metal scale. With transparent gummed tape, attach the tube to an index card, as shown in Figure 1. The bulb should project about two centimeters from the edge of the card. Fill a tumbler with crushed ice and add some water to the ice in the tumbler until it almost overflows. Stir this mixture gently for about thirty seconds. This mixture of ice and water will maintain a fixed temperature for several minutes. Therefore, this temperature can serve as a standard temperature. Place the bulb of the thermometer in the mixture, and hold it there until the liquid in the thermometer stops moving. Try to keep the card from getting wet. Make a mark on the card next to the top of the liquid in the tube. Next, heat some water in a pan until it is boiling gently; lower the heat to prevent rapid boiling, but be sure to maintain a gentle rolling boil. Pierce a small hole in the center of a piece of aluminum foil. Then, cover the pan with the foil. Insert the thermometer tube through the hole, so that the bulb is just above the boiling water. Watch the liquid in the thermometer. It may bob up and down slightly

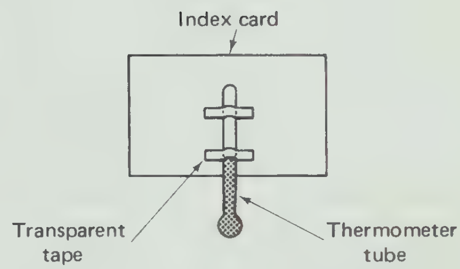

FIGURE 1

if the hole in the aluminum foil is too large, or if an air current blows across the pan. When the top of the liquid is steady, make a mark on the card to show the position of the top of the column.

Increase the heat under the pan to make the water boil more vigorously. Is there any change in the level of the liquid in the thermometer tube? Decrease the heat, but keep the water boiling. Is there any change in the level? Remove the pan from the stove, or turn off the heat so that the water stops boiling. Do you notice any change in the level?

You have been doing what Celsius did when he invented his decimal scale for measuring temperature. He decided to call the temperature of a mixture of ice and water *0* (zero) on his scale, and the temperature of boiling water, *100*. As you probably noticed, it is easier to keep the top of the liquid column steady when it is in ice water than when it is in boiling water, so the zero mark on your scale is probably more accurate than the 100° mark.

Atmospheric pressure is another factor that affects the 100° mark. As you know from listening to weather forecasts, atmospheric (barometric) pressure changes continually. The boiling point of water changes with atmospheric pressure, and it is only at one particular pressure that water boils at 100°C. Atmospheric pressure also changes with altitude (See Figure 2), and so does the boiling point of water. At the altitude of Denver, for example, water boils at close to 95°C.

If you make your boiling point measurement at sea level on a fine sunny day, the mark on your card is probably close to 100°C. If you make it at some other altitude, it is probably at some temperature between 90 and 100°C. For now, though, assume the mark is at 100°C. Measure the distance between the two marks on your card and divide it into ten equal divisions. You now have a Celsius thermometer calibrated in 10° intervals. Mark these intervals from 0 to 100°. You can use your thermometer to read temperatures to the closest 10° mark or interpolate between them for intermediate readings. What is the temperature of the room? Of a glass of cold water?

So far we have not tried to define temperature, and we will not attempt a precise definition now. Let us just say that temperature refers to the hotness or coldness of objects, and that it can be measured with a thermometer.

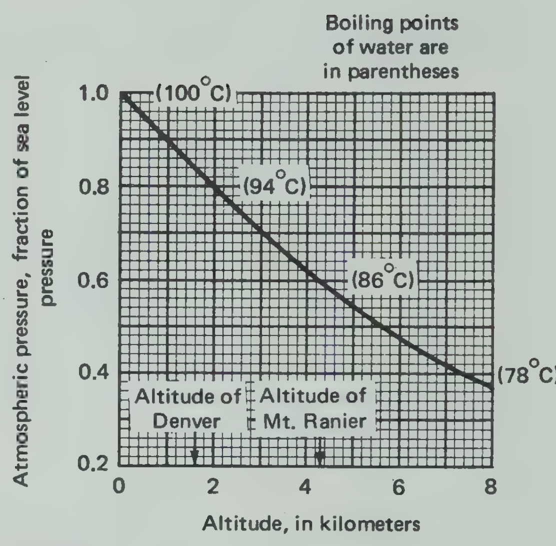

FIGURE 2

MEASURING HEAT

Scientists make a distinction between *temperature* and *heat.* Temperature, as you have just seen, is the measure of the hotness or coldness of an object. Heat is the measure of the agent

that makes things get hot. The distinction can be confusing as Professor Eric Rogers points out:

> It is unfortunate that scientists have chosen to differ from ordinary talk and newspaper vocabulary over the common word "heat." We say "blood heat," "heat of bath water" and read about the "heat of the day." In all these cases, scientists would say temperature. They reserve the word heat for the mysterious agent provided by fuels to make things rise in temperature. Between them, the scientists and the journalists have made a muddle of the word. It is not the journalists' fault. We too should accept the colloquial practice; use "heat" for the thing a thermometer measures and find some other word, perhaps the old name "caloric," for the thing that makes things hotter, the thing that we find is a form of energy. However, we cannot change the scientists' practice either, so we must learn to live with the quarrel. The best you can do is to use the words "temperature" and "heat" in the scientists' manner while you are dealing with scientific matters.*

With these comments of Professor Rogers in mind, make a simple investigation to see how heat (as defined by a scientist) can be measured. For your investigation, you will need the thermometer you have just calibrated, a small stone about the size of a baby's fist, and some kitchen tongs. If you do not have kitchen tongs, you can use a piece of bare wire about 50 centimeters long that can be tied securely around the stone.

Place the stone on a burner of a stove and turn the burner on. While the stone is heating, put 250 milliliters of water in a pan. If your measuring cup is not calibrated in milliliters, put one cup of water in the pan. (One cup of liquid measure is almost 240 milliliters.) Stir the water with a spoon to make the temperature uniform throughout. Immerse the thermometer bulb in the water, observe and record the temperature.

By this time, the stone should be pretty hot. Remove it from the stove with the tongs (or the wire) and slowly lower it into the water until it rests on the bottom of the pan. Stir the water gently with the spoon, observe and record the temperature of the water. Compare this temperature with the original temperature. It is *higher* than the original temperature.

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*Eric Rogers, *Physics For The Inquiring Mind.* Princeton University Press, 1960, p. 412. Reprinted by permission of Princeton University Press.

Many people use the words *hotter temperature* or *warmer temperature* when they mean higher, or greater degree number. You should try to avoid this confusion. Remember that temperature is measured in degrees and therefore, any reference to temperature comparisons must indicate a *higher* or *greater* number of degrees compared to a *lower* or *lesser* number of degrees. The water may indeed be hotter now than it was before you put the stone in it, but it is not at a *hotter temperature.*

How did the water get hotter? How did the temperature of the water increase? *Heat* passed from the stone into the water. We can make a general statement: Whenever the temperature of a substance is increased, it is increased because heat has been absorbed by that substance. (The converse of this statement is not always true, as you will see in a moment. Sometimes, even though heat has been absorbed by a substance, the temperature remains the same.)

How much heat was absorbed by the water? If you assume that no water evaporated when the stone was immersed, you can determine how much heat was absorbed by the water from a comparison of the original and final temperatures, since you know the quantity of water involved.

The unit in which heat is measured in the metric system is the *calorie.* The operational definition of a calorie is: The amount of heat absorbed by one milliliter (or more accurately, one gram) of water when its temperature is increased one degree Celsius. Suppose that the original temperature of the water was observed to be 15°C; after the stone was immersed and the water stirred again, its temperature was found to be 26°C. The temperature increase was 11°C.

The temperature of each milliliter of water increased 11°C and each required 11 calories. There were 250 milliliters of water, so 250 x 11 calories were required to increase the temperature 11°C. The stone imparted 2,750 calories of heat to the water.

Now try the experiment a little differently. This time, put 250 milliliters of a mixture of crushed ice and water in the pan. This mixture, as you know, is at a temperature of 0°C. Add the heated stone, stir, and measure the temperature. Although some ice melted, you probably observed that some is still present and that the temperature of the mixture remained at 0°C. Since you still have a mixture of ice and water, a thermometer immersed in the mixture after stirring, still shows a temperature of 0° (or very nearly 0°).

The temperature did not change. But some of the ice melted. Suppose you weighed the ice and found that 125 milliliters had melted, absorbing heat from the stone to do so. If you knew how many calories of heat left the stone and

were absorbed by the ice when it melted, you could calculate the number of calories required to melt one milliliter of ice. You need not bother with the calculations, but careful measurements made by others have shown that 80 calories are required to melt one gram of ice at 0°C.

Whenever heat is absorbed by a substance, either its temperature increases, or the temperature remains the same while the substance changes its state; it melts if it is a solid; or it vaporizes if it is a liquid. Sometimes solids—dry ice is an example—change from a solid to a gas when they absorb heat. From this statement, you can construct an operational definition of heat. Heat is something which, when absorbed, either causes a temperature increase or a change of physical state (from solid to liquid, or from liquid to gas). Thus, the absorption of heat is indicated either by an increase in temperature or by a change of state.

The quantity of heat (the number of calories) absorbed can be determined by a calculation. If the absorption of heat causes a change in state but no change in temperature, you need to know the amount of substance which changed its state and the number of calories required for a unit amount to change state. If the absorption of heat causes only a change in temperature, you need to know the following: the amount of substance whose temperature increased; the number of calories required for a unit amount of the substance to increase one degree Celsius, and the number of Celsius degrees the temperature increased.

VARIOUS WAYS TO PRODUCE HEAT

Heat for everyday use is commonly produced from electricity, coal, oil, or natural gas. The stone you heated on the stove got its heat either from the burning of natural gas (a chemical reaction) or from electricity passing through a heating element (a physical reaction). The electricity may have been generated in a power plant that burns coal (a chemical reaction), or a hydro-electric power plant (physical reaction). Coal, oil, natural gas, and electricity are used for heating houses.

You are familiar with other ways to produce heat. Rub the palms of your hands rapidly together. What do you feel? Did your palms get warmer? Why? You probably said, "Because of the friction," and that is partly correct. But it was not just the friction between your palms; it was the work you did to make your palms move back and forth past each other rapidly. There are other familiar ways to get heat by doing work: pull a large nail out of a board, pump a tire with a handpump, bend a piece of wire quickly back and forth, and

so on. In Science...A Process Approach children investigate heat production by doing work on a heat generating apparatus in Exercise q, Experimenting I2, Variables Affecting Heat Production.

Heat is produced in many chemical reactions. We are personally involved in producing heat all the time. The food we eat supplies energy for our activities, and also energy to keep us warm. So much heat is produced during the metabolism (chemical reactions) of the food we eat that our bodies have special mechanisms for getting rid of heat. The energy of food is usually expressed in calories. The calories that we talked about earlier are not the same as the calories we are concerned about in dieting. One thousand of these *water calories* (also called small calories) make one *diet calorie* (also called large calorie). A diet calorie is called a *kilocalorie.* One kilocalorie of heat raises one kilogram of water one Celsius degree. As an example, if the temperature of 700 milliliters of water were raised from 35° C to 50° C, an increase of 15 Celsius degrees, we can calculate that the water absorbed 700 x 15 calories, or 10,500 calories. This would be 10.5 kilocalories or diet calories.

Suppose that your average daily food intake is 2,000 large calories. If all of this food were burned and used to raise the temperature of water from 0° to 100° C, how much water would it heat? (Since one large calorie or kilocalorie raises the temperature of one kilogram of water one degree Celsius, it takes 100 large calories to raise the temperature of one kilogram of water from 0° to 100°C. But your food intake is 2,000 large calories. If all this food were burned, it would provide enough heat to raise the temperature of 20 kilograms of water from 0° to 100°C.)

FORCES AND PRESSURE

A force is a push or a pull. One of the simplest ways to measure a force is with a spring. If you pull on a spring like the one used for a spring scale, it will extend. The amount of the extension is a measure of the force. Some springs, such as coil springs on an automobile, are made so they can be compressed (the coils are not tight). If you push on such a spring, it gets shorter (compresses). Pull on it and it gets longer (extends). This kind of spring could be used to measure either push or pull.

Forces also have *direction.* A push or a pull is always exerted in some direction. You pull *up* on the handle of a suitcase to lift it. You push *forward* on a shopping cart, and you can describe this direction of push geographically, such as *north* or *east.* When describing forces, you usually specify both *how much* and in *what direction.*

FORCES WHICH ACT ON A BODY

Perhaps the best way to determine what forces are acting on a body is to imagine that a line or surface goes all the way around the body. Then, ask yourself, "What forces (pushes or pulls) are exerted *on* the body *inside* the imaginary enclosure *by* objects *outside* the enclosure?" There are two types of forces: *contact forces* (when two bodies are actually touching) and forces which act at a distance (when two bodies are not actually touching). You are probably more familiar with forces acting at a distance than you realize. These forces are gravitational forces (earth-pull), magnetic forces, and electric forces. The earth pulls on an apple, and the apple falls to the ground; this is force acting at a distance because nothing touched the apple until it hit the ground. Another kind of force acting at a distance is the magnetic force that makes

a nail jump from a table up to a magnet. Nothing touches the nail until it hits the magnet. You probably have had the experience of combing your hair and then finding that you could pick up a small piece of paper with the comb. This is an example of electric force.

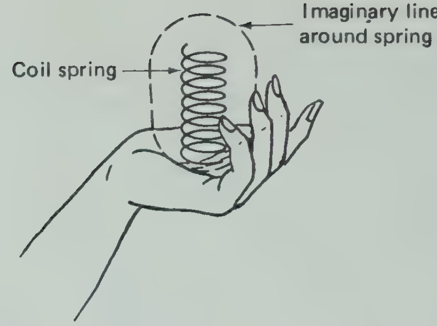

FIGURE 1

Suppose that you are holding a coil spring in the palm of your hand. What forces are acting on the spring? In your imagination, draw a line around the spring. (See Figure 1.) What forces are acting across that line? Are you pushing up on the spring? What would happen if you did not push up on the spring? (It would fall to the floor.) The only other force acting on the spring is the earth-pull, or weight of the spring. This is in the *downward* direction. You have now found the forces which are acting on the spring: the pull of the earth on the spring *down* and the push you exert *up*. If these forces are the same in amount, but opposite in direction, the spring will not move up or down.

Suppose someone pushes down on the top of the spring as you hold it in your hand. There is a push *down* on the top, and there is still the earth-pull *down*. You still push *up* on the bottom of the spring, but your push is greater now than before. You have to push up harder on the spring now, or else your hand and the spring will move down.

If you place the spring on a table instead of supporting it with your hand, and if you push down on the spring, what forces would now be acting on the coil? Remember, draw an imaginary line around the spring. The earth pulls *down* on the spring; you push down on the top of the spring. What other possible forces are there? Does the table actually exert a force (push) *up* on the spring? Yes, it must; if it did not, the spring would fall. You might say that the spring doesn't know whether a table or a hand pushes up on it, but something has to exert an upward force on the spring if it is not to move downward.

You can probably think of a number of examples of inanimate objects exerting forces on you or on other objects. Lean against a wall. You can feel the wall push against you to support you. If you do this with your eyes closed, it is easy to imagine someone just behind the wall pushing to keep you up. Fasten a string to the knob of a door that is closed. Now, pull on the string. With your eyes closed, you don't know whether someone is pulling on the other end of the string or whether it is the doorknob pulling.

In the preceding example, with the spring on the table, how could you find the forces exerted on the table? How can there be forces exerted on the table when it's easy to see that the table isn't doing anything? As usual, there is the earth-pull *down* on the table. Also, the spring resting on the table

pushes *down* on the table. (Note that it is not the hand which pushes directly down on the table. The hand does not touch the table; it is the spring which touches the table. (See Figure 2.) Since the legs of the table touch the floor, the floor pushes up on them. You could imagine a circus strong-man holding the table above his head; to support it he must push up on the table. Of course, he must be standing on something which supports him!

REPRESENTING FORCES WITH ARROWS

Forces can be represented with arrows. The head of the arrow indicates the direction in which the force is acting. The length of the arrow indicates roughly the magnitude of the force. For example, the forces acting on the spring and the table, shown in Figure 2, may be indicated with arrows, as in Figure 3. Notice that the arrows representing opposing

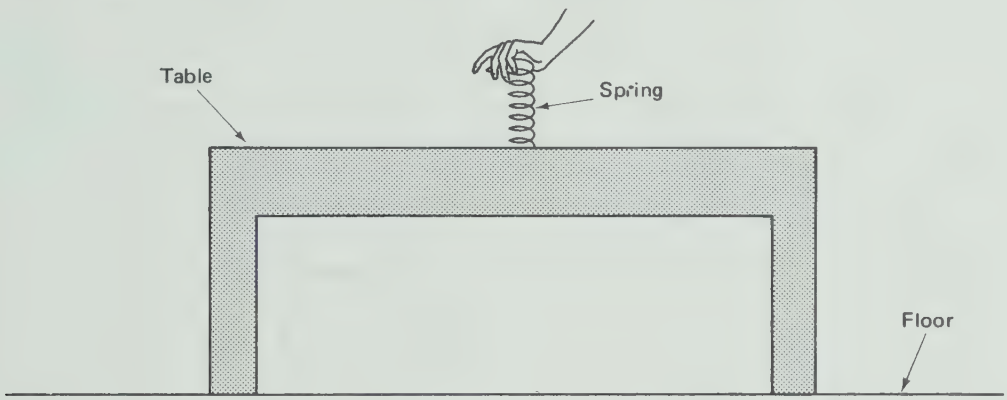

FIGURE 2

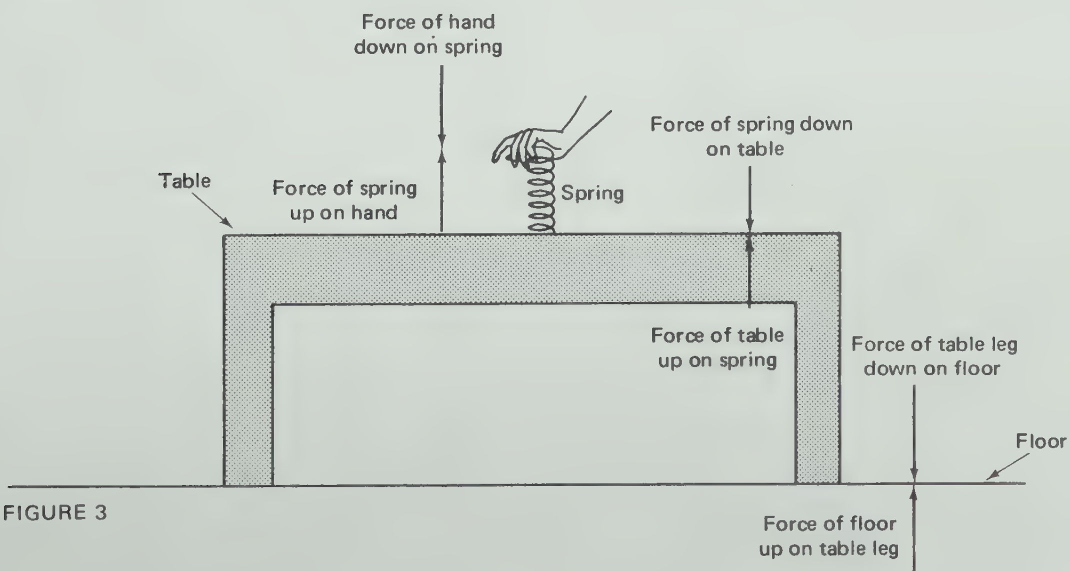

FIGURE 3

forces are the same length. If the arrows were different lengths, the object would move in the direction of the larger force.

Suppose you drop a golf ball from your hand. What forces act on the golf ball after it leaves your hand? (See Figure 4.) If you visualize a surface enclosing the ball, you will see that the only forces which can be acting on the ball are earth-pull (downward) and a small force exerted upward on the ball by air friction. (We could eliminate this air friction by dropping the golf ball in a vacuum.) The downward force on the ball is much larger than the upward force on it, so the ball will accelerate downward.

FIGURE 4

PRESSURE

For some purposes, it is important to consider the area on which force acts. Pressure is defined as force per unit area, or

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

Place one hand palm up on the table. Hold a pencil in a vertical position with the eraser touching the palm of your hand. Press hard on your palm with the pencil. Next, put a small book on the palm of your hand. Stand the pencil on the book and press hard on the pencil. Did the second situation feel different from the first? If you pressed hard enough, you probably found the first situation painful. If you pressed with the same force each time, the pressure on your palm was greater in the first case than in the second.

Suppose that in each situation you exerted a force of 10 newtons with the pencil. The area of the end of the eraser was probably about 0.25 square centimeter. Then, the pressure on the spot on your palm under the end of the pencil was about 40 newtons per square centimeter. Next, suppose that the area of the palm of your hand is 70 square centimeters and that the small book covered your whole palm. If you pressed on the book with a force of 10 newtons, what would be the pressure on your palm? The 10-newton is now pressing on 70 square centimeters instead of 0.25 square centimeters. Using the formula, Pressure = $\frac{\text{Force}}{\text{Area}}$, where force is 10 newtons, and area is 70 square centimeters, then $\frac{10}{70} = 0.14$. The Pressure is 0.14 newton per square centimeter. Does this explain why the first situation was more painful than the second?

You are probably familiar with barometric pressure that is always included in weather reports. Changes in air pressure, together with other weather information, can be used to predict changes in weather. At sea level, the average atmospheric pressure is about 10 newtons per square centimeter. This is

the same pressure you would get by resting your box of *Science—A Process Approach* exercises (which weighs close to 10 newtons) on a 1-centimeter cube.

Here are some other examples of instances where pressure is an important factor: Air pressure in automobile tires, pressurized cabins of airplanes, and gas and water pressure in pipelines. Scuba divers must pay close attention to water pressure. If a scuba diver stays very long at depths of thirty meters or so, the water pressure on his body forces nitrogen into his blood stream where it dissolves. When he returns to the surface, the nitrogen bubbles out of solution and he gets the bends.

The earth-pull on 100 grams of water is 0.98 newton. Remember that 1 milliliter (1 cubic centimeter) of water weighs 1 gram. A column of water with a cross section of 1 square centimeter and a height of 100 centimeters would therefore have a mass of 100 grams. The pressure at the bottom of the column is 0.98 newton per square centimeter. What is the water pressure at a depth of 10 meters? (10 x 0.98 or 9.8 newtons per square centimeter.) Air pressure at sea level is about 10 newtons per square centimeter. How does this compare with water pressure at a depth of 10 meters? (They are very nearly the same.) What is the total pressure on a diver 10 meters below the surface of the water? (The sum of the air pressure and the water pressure, or 10 + 9.8 or 19.8 newtons per square centimeter.)

MASS

Mass is the name given to a property of matter that might be called ***difficult-to-moveness***. Mass is a measure of ***inertia,*** which can be defined as the resistance an object has to any change in motion. It is the property that makes it hard to stop a moving object, or hard to start moving an object that is still. Objects with more mass have greater inertia than objects with less mass. You know how much harder it is to slide a desk across the floor than to slide a chair. To add to the clarity and accuracy of the statement, it should be assumed that the chair and desk are pushed across very slippery ice. On a frictionless surface the force required to cause the same accelerations for the two objects would be different, and this difference would be directly attributable to the difference in mass. The masses of objects can be compared by comparing the forces required to cause them to change their speeds by the same amount in the same time.

An operational definition of mass might be as follows. You have two identical frictionless carts. However, one has a load on it. Measure the forces needed to accelerate both carts uniformly to the same speed in the same time. If the force required to accelerate the loaded cart is twice the force required to accelerate the unloaded cart, than the loaded cart has twice the mass of the unloaded cart.

The mass of an object does not change. If you took the two frictionless carts to the moon and repeated your observations there, you would find that the force required to accelerate the loaded cart would be twice the force required to accelerate the unloaded one. The forces would be the same as the forces you measured on earth. If, on your return trip from the moon, the two carts were floating motionless in the air of your space craft, and you measured the force required to accelerate each of them uniformly to the same speed in the same time you would find again that one force was twice the other. The measures of the forces would be the same as the measures you made on the earth and on the moon.

MEASURING MASS

In *Science—A Process Approach,* mass is measured in two ways. It is not easy to measure the force required to accelerate an object to a certain speed, so that method is not used. Instead, the resistance to being moved is measured by placing the object in the pan of the vibrator shown in Figure 1. The pan is attached to a springy steel strip, like a hacksaw blade. This steel strip provides the force for speeding up the pan and the object in it. If the strip is held to one side and released, it will vibrate back and forth and, finally, after half a minute or so it will stop (because of frictional forces in the strip). Now, if the steel strip is held the same distance to the side each time, it will be exerting the same force on the pan and whatever objects are in it. This force will speed up an object of small mass more rapidly than it will one of greater mass. So the greater the mass in the pan, the more slowly the vibrator will vibrate. If you calibrate the vibrator with standard masses, counting the number of vibrations in a specified time (say one minute), you can then use the vibrator to measure masses of unknown objects. This is one of the activities in *Mass, Defining Operationally 5, Exercise f,* Part F.

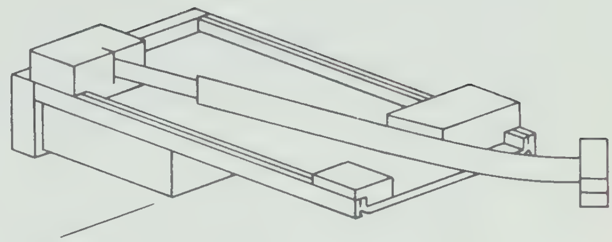

FIGURE 1

The equal-arm balance is the second device that is used to measure mass. If an object is placed in one pan of an equal-arm balance and standard masses are added to the other pan until the arm of the balance is horizontal, then the mass of the object is the same as the sum of the standard masses. The object is exerting a force down on one pan that makes the balance arm tend to go down (rotate around the knife edge at the center of the beam). When standard masses are put in the other pan, they also exert a force tending to make that pan go down. When the forces on both pans are equal, the arm of the balance is horizontal.

MASS AND EARTH-PULL

Earth-pull or gravitational force can be described in mathematical terms, but it is not easy to explain why it exists. Why do objects attract each other? A stone falls to the earth, the moon revolves around the earth, and the earth revolves around the sun. There is no easy explanation. The fascinating fact about the earth's gravitational force is that the size of the force that acts on an object is proportional to the mass of the object. A mass of 2 kilograms is attracted to the earth with twice the force of a mass of 1 kilogram. And the same is true on the moon. The difference on the moon is that, because the moon is smaller (has less mass) than the earth, the forces with which it attracts the 1-kilogram and the 2-kilogram objects are smaller than on the earth. But still the moon-

pull on the 2-kilogram object is twice that of the 1-kilogram object.

Could you use an equal-arm balance to compare masses on the moon? Yes, if there were equal masses in the opposite pans of the balance, the balance arm would be horizontal. There would be the same moon-pull on each pan.

Could you use an equal-arm balance to compare masses in a space craft orbiting the earth? You should be able to answer that question after you have read the paper, *Weight and Weightlessness.*

WEIGHT AND WEIGHTLESSNESS

Weight is the measure of the earth-pull on an object. In the last section of the paper on *Mass,* we discussed the fact that the force of earth-pull on an object is proportional to its mass. The earth-pull (which is commonly called *gravitational force*) on an object that has a mass of 2 kilograms is twice the pull on an object with a mass of 1 kilogram. Therefore, the weights of two objects are proportional to their masses.

Weight can be measured by any device that measures force. Spring scales and bathroom scales are two such devices. Notice that weight is always a *force down.* It has both amount (stretch of a spring) and direction (down). For all practical purposes, the weight of an object is the same anywhere on Earth. An object weighs a little less on a high mountain than at sea level. It weighs a little more at the poles than at the equator. But in no case is the difference more than 0.5%*.

With the landing of astronauts on the moon, weight becomes a practical problem, because the moon's mass is smaller than the earth's. Moon-pull is only one-sixth as great as earth-pull. So, someone who weighs 600 newtons (about 135 pounds) on the earth would weigh only 100 newtons (23 pounds) on the moon. What a marvelous way to lose weight, but unfortunately not mass.

Because the forces exerted by muscles are the same on the moon as on the earth, reactions to muscle movements are greater on the moon than on Earth. If a man can broad-jump two meters from a standing position on the earth, he should be able to broad-jump twelve meters on the moon! And a football player who can punt half the length of a football field on the earth could punt the length of three football fields on the moon. Football fields on the moon would need to be over half a kilometer long!

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*See also the background paper, *Metric System.*

WEIGHTLESSNESS

Ever since astronauts started circling the earth, we have all been aware of what is called *weightlessness.* We have seen television pictures of astronauts in their space craft. Objects—including the astronauts themselves—unless fastened down, float freely in the air of the cabin. Why is this so? Does it mean that there is no force exerted on the spacecraft by the earth? No indeed! If the earth were not exerting a force on it, the spacecraft would fly off into space.

How then can an object that is being acted on by earth-pull be weightless? The explanation is not difficult. First, imagine that you are in a rapidly descending elevator. Standing on a scale in the elevator, you notice that you weigh less than you normally do. If the elevator accelerates fast enough, the scale will indicate that you have zero weight. You will be weightless! (Of course, you will get a rude shock if the elevator stops suddenly. Your weight or force down, for a moment will be much greater than normal.) The point is that if you are in an elevator that is falling freely towards earth, you are falling too, and you do not exert any force on the floor and the floor does not exert a force on you. (See Figure 1.) Perhaps you have experienced the feeling that the floor of a descending elevator was falling away from you.

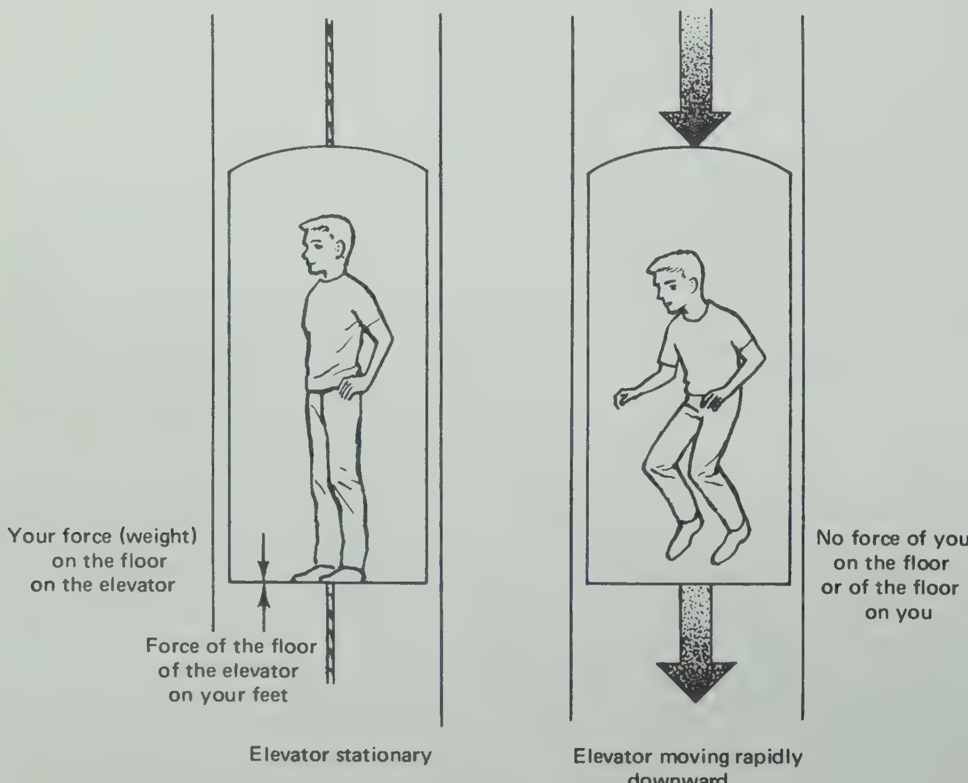


FIGURE 1

Now, how is this related to what happens in a spaceship in an orbit around the earth? Is the spaceship accelerating like the falling elevator? Yes, it is. At any instant of time the spaceship is moving at a high speed in a direction parallel to the earths surface as shown in Figure 2(a). If the spacecraft were not affected by the gravitational pull of the earth it would continue to travel in a straight line and off into space.

However, the earth pulls on the spacecraft, forcing a continuous change in direction. Thus, after a short time has elapsed, the spacecraft will be traveling in a new direction but at the same speed as shown in Figure 2(b). It has actually fallen toward the earth away from its straight-line path. It maintains its orbital path because its speed parallel to the surface of the earth is just right, so that its fall from its straight-line path keeps it at a constant height above the earth. You might say that it is falling around the earth. And so is everything in it: the astronauts, their cameras, food, and all the rest of their gear. And since the astronauts and space capsule are falling together, the astronauts are weightless, just like the man in the freely falling elevator.

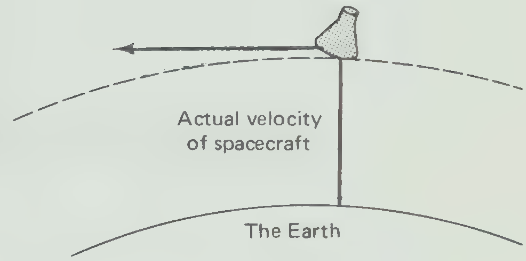


Figure 2(a)

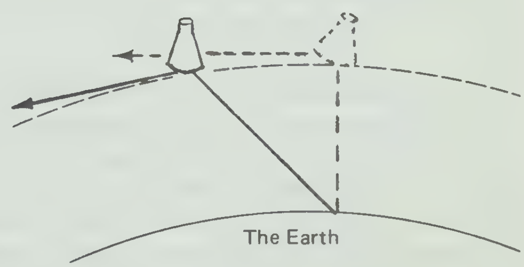


Figure 2(b)

VELOCITY AND ACCELERATION

In everyday terms, speed and velocity are often considered synonymous, and acceleration is understood to describe an increase in speed. However, in the context of *Science—A Process Approach,* these three words are used in the way scientists use them. To understand these words, it is suggested that you imagine a series of actions, though if you wish you may actually carry these out. If you do want to be this realistic, be sure your automobile insurance is up to date and that all the traffic policemen in the area are eating lunch!

For your imaginary trip, you will need an automobile with a broken speedometer. The speedometer is the moving needle and scale on the instrument panel. It is not the gadget that indicates miles traveled; that gadget is properly called an *odometer.* The odometer must be in operating condition for this activity. Also, you will need a stopwatch, a magnetic compass, and a spirit level (as is used by a carpenter).

SPEED

Imagine you are driving your car on a straight, level road. At a convenient moment, note the odometer reading and start the stopwatch. Keep a constant unchanging rate of motion as you go down the road. After a minute or so, note the odometer reading again and stop the stopwatch. Divide the distance you traveled by the elapsed time. The quotient is the *speed* you maintained over the distance traveled. The speed comes out to be a small part of a mile per second, if your stopwatch is calibrated in seconds and if the odometer reading is in miles. This can be converted to miles per hour.

The experiment you have just imagined is similar to the operation carried out by the speedometer in your car. The speedometer is a simple-minded computer which can divide

the number of miles traveled in a short time interval by the measure of the time interval in hours. The quotient is presented as the position of a needle on a number scale. You can define speed in several ways: the indication of the speedometer needle on the scale, the quotient of measures of distance and time, or the rate of change of distance with respect to time.

VELOCITY

Velocity is defined as speed traveled in a given direction. Thus, if your speed is fifty kilometers per hour, your velocity might be fifty kilometers per hour *north.* If you are going up in an elevator, your speed might be 0.9 meter per second, but your velocity would be 0.9 meter per second *up.*

Let's go back to your imaginary trip. Set the spirit level and compass on your lap, pull out from your parking place, and drive down the road; keep your eye on the spirit level, the compass, and the speedometer needle. Keep your speed constant. Now, as you come to a curve, watch the compass needle as you go around the curve. Did the compass needle move? That is, did the compass move and did the needle remain pointed in the same direction as before? (Yes.) Did your speed change? (No.) Did your velocity change? (Yes, you changed direction.)

Try another. As you drive down the road, keep your speed constant. The road is straight, but notice the gentle hill ahead of you. Keep your speed constant, and watch the spirit level as you climb the hill. Did the velocity of you and the car change? (Yes, the direction changed. It was, for example, east and horizontal before going up the hill. As you went up the hill, your speed was still the same, but the direction was now east and up. As a result, the velocity changed.)

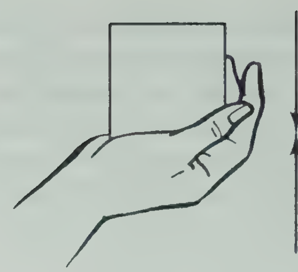
VECTOR REPRESENTATION

A *vector* has magnitude and direction. In this program, children have experience with forces and with velocity. Both of these can be represented as vectors. Vectors are discussed in the background paper on *Forces and Pressure* and are used to represent velocities in the paper on *Using Space/Time Relationships.* You may want to review these papers if your questions about vectors are not answered in the following examples.

When you hold an object in your hand, there are two forces acting on it. The force of gravity pulls down on the object, and your hand pushes up on the object to keep it from falling. Since the forces are equal and opposite in direction, the object is stationary. The children learn to represent these forces

by arrows as shown in Figure 1(a). The lengths of the arrows, or vectors, represent magnitude and the arrowheads designate the directions in which the forces are acting. Figure 1(b) shows a small cart in motion in the direction of the longer vector.

Similarly, velocities, which have magnitude and direction, can be represented by vectors. Suppose your car moves at a constant speed of 60 kilometers per hour east. Later, you slow down as you turn south and drive 30 kilometers per hour. These velocities are shown as vectors in Figure 2.



1a

FIGURE 1 (a)

1b

FIGURE 1 (b)

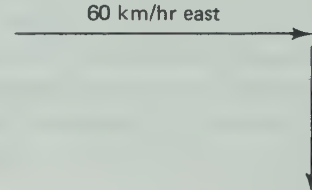


FIGURE 2

ANGULAR SPEED AND VELOCITY

Your imaginary trip has thus far been concerned with linear speed and velocity. In this program, the children also study angular speed and velocity. If you were driving a car on a circular path, perhaps a circular race track, you could refer to the rate of change of direction or angle rather than rate of change of distance. If you did, you would be reporting *angular speed.* The most commonly based unit of measure of angular speed is *revolutions per minute (rpm).* If you traveled around a circular path 10 times in 5 minutes, your angular speed is 2 revolutions per minute. Once around the circle is *a revolution.* The designations used for phonograph records, such as *33 1/3, 45,* and *78 revolutions per minute,* are measures of angular speed.

In some fields of science, the words *rotation* and *rotate* are commonly used to describe the motion of an object spinning about an internal axis, whereas the words revolution and revolve are used to describe the motion of an object that moves about an axis external to itself. Thus, astronomers say that the earth rotates on its axis once in 24 hours, and that the earth revolves around the sun once a year. However, both scientists and laymen frequently use these words interchangeably.

As you drive around a circular path, you are constantly changing direction. What is the difference between angular speed and angular velocity? What meaning can you attach to *change in direction* when you are traveling a circular path? Direction may be *clockwise* or *counterclockwise.* You may report that your angular speed is 2 revolutions per minute, and that your angular velocity is 2 revolutions per minute counterclockwise. In science and mathematics, the counterclockwise rotation is usually designated as being in the positive direction and the clockwise rotation as being in the negative direction.

There are two exercises concerned with angular speed. In *Describing the Motion of a Revolving Phonograph Record, Measuring 13, Exercise f,* Part D, the children observe the

motion of a phonograph record. In *Rotation and Linear Speed, Using Space/Time Relationships 17, Exercise t,* Part E, they learn to relate linear and angular speed.

ACCELERATION

Return now to your imaginary investigations. Drive on a straight stretch of road, keeping your speed constant, watching the speedometer and the objects on your lap. Brake gently. What instrument indicated a change? (The speedometer needle changed; it showed that your speed decreased.) The rate of change of speed is called *acceleration.* When you are moving in a straight line at a constant speed, your acceleration is zero; if you change your speed, you are accelerating. If you slow down, the acceleration is said to be *negative;* if you speed up, you are accelerating *positively.*

Your children will have experience in speeding up and slowing down moving carts in their science classes. They will be accelerating the carts. Out of school they will no doubt accelerate their bicycles and often their rate of motion of walking, running, and playing. When you drive home remember not to press too hard on the accelerator! Is the brake an accelerator?

In several exercises on falling bodies, the children observe that velocity increases as the distance of fall or roll increases. The body falling or rolling down is accelerating. They will learn that the speeding up (change in velocity) is caused by the force of gravity on the body. In other words the force *of gravity produces an acceleration. The relationship* $d = \frac{1}{2} gt^2$ shows the distance moved by a falling body, where d represents distance fallen, *t* represents time, and *g* is the *acceleration constant,* or the *acceleration of gravity.* In the metric system, *g* is 9.8 meters *per second per second.*

Why does the unit of time appear twice in the unit of acceleration? Velocity is a rate of change of distance with respect to time, and acceleration is a rate of change of velocity with respect to time. Nine and eight tenths meters per second per second means the velocity is changing each second at the rate of 9.8 meters per second.

RELATIONSHIP BETWEEN DISTANCE AND TIME, AND SPEED AND TIME

Suppose you drive your car on a straight path at a constant speed of 10 kilometers per hour. You know that your distance, *d,* from your starting point at any time, *t,* is given by the relation, $d = 10t$. Figure 3 shows a graph of this relation. Is it a linear relation? (Yes, the graph is a straight line.) What is the slope of the line? (10; between any two points on the

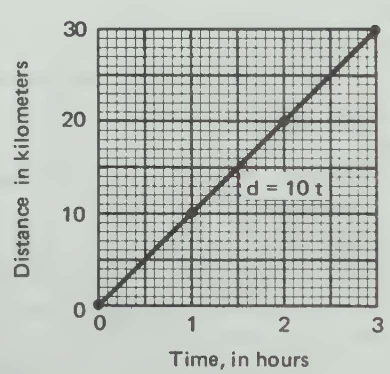


FIGURE 3

graph, the change in the distance-coordinate divided by the change in the time-coordinate is 10.) In other words, the speed is the slope.

Next, suppose you accelerate your car, 6 kilometers per hour, each hour. That is, you start your car and accelerate it smoothly so that at the end of the first hour the speed is 6 kilometers per hour. If you do this carefully, the relation associating speed and time is linear. Assuming you start from rest, your speed, s, is given by the relation, $s = 6t$.

This linear relation is shown as a graph in Figure 4. What is the slope of this relation? (6) You see that the slope of the relation between speed and time is the acceleration, just as the slope of the relation between distance and time is the speed. But this should not surprise you when you recall that speed is the rate of change of distance with respect to time; acceleration is the rate of change of speed with respect to time.

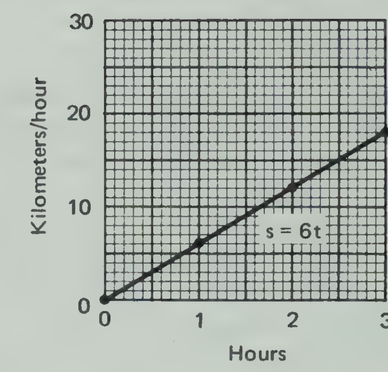


FIGURE 4

In this second situation, in which you are accelerating your car in a straight path of 6 kilometers per hour each hour, your distance traveled is given by the relation, $d = 3t^2$. Note the similarity between this relation and the relation for distance of fall in time, t, given on page 224. A graph of the relation, $d = 3t^2$ is shown in Figure 5. It is a nonlinear relation.

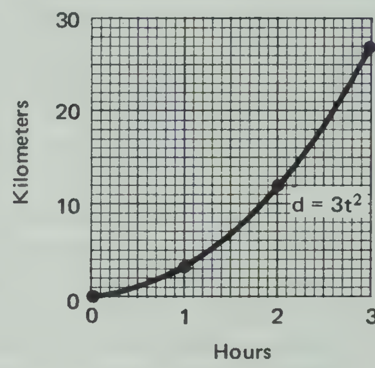


FIGURE 5

EVALUATION

If you would like to check your understanding of some of the ideas presented in this paper, answer the following questions. For questions 5–7, use 3.1 as the ratio of the circumference of a circle to its diameter. When you have completed your work, refer to the *Comments on Questions* section which follows. You may also wish to refer back to the discussion and questions on the circumference and diameter of a circle in the exercise on *Using Space/Time Relationships* in this book.

1. In a track meet, a runner ran the distance in 75 seconds. Is this a statement of speed or velocity?
2. Later, in the same track meet, a hurdler ran in a competition in which there were six hurdles. Did he change his velocity at any time as he carried out his athletic assignment?
3. Is it possible to travel along a straight, horizontal road and not accelerate?
4. Is it possible to travel in hilly country on a road, by foot or by any other means and not change your velocity?
5. A boy is running alongside his friend who is riding a bicycle. How fast must the boy run to keep up with his friend, if the bicycle wheels, 80-centimeters in diameter,

are turning 50 revolutions per minute?

6. Three concentric wheels, *A, B,* and *C,* are shown in Figure 6. The diameters of the wheels are 20, 40, and 60 centimeters respectively.

   (a) If all three are turning at 4 revolutions per minute, how many centimeters along the circumference will each point move in one minute?

   (b) Suppose the mechanism is arranged so that each of the three points, *A, B,* and *C,* travels the same distance in one minute. How fast will the *A* wheel and the *B* wheel have to turn so that Points *A* and *B* travel the same distance as point *C*? The large wheel is turning 4 revolutions per minute.

7. If you drive your car 93 kilometers per hour, how many revolutions per minute will your front wheels be turning? (You estimate that their diameter is 70 centimeters.)

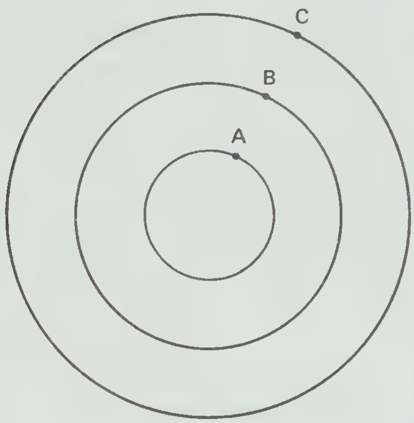


FIGURE 6

COMMENTS ON QUESTIONS

1. Neither. To know the runner's speed, you need to know how far he ran in 75 seconds. To know his velocity, you need to know this distance and his direction.
2. Yes, several times. His speed changed from zero before the starting gun to several meters per second immediately after the gun was fired. His direction changed as he leaped up over the first hurdle. It changed again downward at the top of the leap, and changed again to a horizontal direction at the end of the downward travel. Probably, as he went over each hurdle, his speed decreased just as he leaped, and increased as he resumed running on the ground after going over each hurdle.
3. Yes, if you don't count the start and the stop, and if the traffic does not cause you to slow down or speed up.
4. No. Going up, down, and horizontally require that your direction be changed from time to time as you traverse the hills, even if you always keep to a path in the same geographical direction.
5. The boy will have to run 12,400 centimeters per minute, or 124 meters per minute. (3.1 x 80 x 50 = 12,400.) Can he run this fast?
6. (a) *A,* 2.48 meters; *B,* 4.96 meters; *C,* 7.44 meters

   A: Circumference is 20 x 3.1

   Circumference = 62 centimeters

   Distance point moves is 4 x 62 centimeters or 248 centimeters or 2.48 meters

   B: 40 x 3.1 x 4 = 496 centimeters or 4.96 meters

C: 60 x 3.1 x4 = 744 centimeters or 7.44 meters

(b) *A* wheel, 12 revolutions per minute
B wheel, 6 revolutions per minute

7. Circumference of front wheels, 70 x 3.1 centimeters

Rate of travel, $\frac{93 \times 100{,}000}{60}$ centimeters per minute

Angular velocity, $\frac{93 \times 100{,}000}{60 \times 70 \times 3.1} = \frac{3{,}000{,}000}{4{,}200} =$

$$\frac{5{,}000}{7} = 714$$

714 revolutions per minute

SCIENTIFIC NOTATION

You and your pupils have seen numbers like the ones in Figure 1. These numbers are expressed in scientific notation. In science, where both very large and very small numbers are used to express counts, estimates, or measurements, scientific notation is very useful. It is a short way of writing numbers, and a convenient form for using numbers in computation.

Science—A Process Approach will have accomplished one of its goals if you and your pupils want to read more about science. In supplementary reading about science, you will almost certainly find scientific notation. For this reason, the basic ideas of this fundamental form of communication are introduced in *Large Numbers, Using Numbers 13, Exercise w,* Part E, and in *Large Numbers, Glurks, and Respiration,* a *Supplementary Exercise* in Part F. Scientific notation can also be used in a number of other exercises in Parts F and G. Use of decimals in the program is almost essential, and the use of powers of 10 can be a very helpful tool for children in identifying relations between two numbers, both expressed as decimals.

Some approximate sizes of things, in meters	
Diameter of an atom	10^{-10}
Diameter of a red blood cell	7×10^{-6}
Height of a man	1.8×10^{0}
Height of the Washington Monument	1.7×10^{2}
Height of Mt. Everest	8.8×10^{3}
Diameter of the earth	1.3×10^{7}
Distance from the earth to the moon	3.8×10^{8}
Distance from the earth to the sun	1.5×10^{10}
Diameter of the solar system	1.2×10^{13}

FIGURE 1

POWERS OF 10

Exponents are a shorthand method of expressing products of equal factors. For example,

$$a \times a \times a = a^3 \text{ and } 10 \times 10 \times 10 \times 10 \times 10 = 10^5.$$

The *3* and *5* in these examples are called exponents. a^3 and 10^5 are called *powers* of the numbers *a* and *10*, respectively. 10^5 is called the *fifth power of 10* or *10 to the fifth power.*

This shorthand has been introduced universally in science and mathematics. While the saving in print and space is probably sufficient to bring about universal acceptance of the no-

tation, the real saving is derived from use of exponents in computation as you will learn in this paper.

The examples given illustrate the definition of an exponent that is a counting number (*1, 2, 3, 4, 5,* and so on). 10^5 is a name for the product of five 10's. 10^9 is a name for the product of nine 10's or

$$10^9 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10,$$

or 10^9 is a name for one billion.

In your reading, you may have seen a number like 10^{-6} or 10^0. Obviously, the definition above does not cover these examples, and a new definition or an extension of the definition is necessary. Again, there is universal agreement. It is instructive to see how the definition has been chosen. A consideration of products and quotients of powers of *10* yields the clue.

$$\begin{aligned} 10^3 \times 10^4 &= (10 \times 10 \times 10) \times (10 \times 10 \times 10 \times 10) \\ &= 10^7 \\ 10^{10} \times 10^{15} &= (10 \times \ldots \text{ up to ten 10's}) \times \\ &\quad (10 \times 10 \ldots \text{ up to fifteen 10's}) \\ &= 10 \times 10 \times \ldots \text{ up to twenty-five 10's} \\ &= 10^{25} \end{aligned}$$

A few examples like this will convince you that products of powers of a number can be found by adding exponents when the exponents are counting numbers. In mathematical symbols this is

$$A^r \times A^s = A^{r+s}.$$

Since division is the inverse of multiplication, you would expect that

$$A^r \div A^s = A^{r-s}.$$

An example with powers of *10* will lead you to infer that this is correct.

$$10^7 \div 10^4 = \frac{10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10}{10 \times 10 \times 10 \times 10} = 10 \times 10 \times 10$$

$$\text{or } 10^7 \div 10^4 = 10^3, \text{ which is } 10^{7-4}$$

But, suppose the exponent in the denominator is equal to or larger than the one in the numerator.

$$10^4 \div 10^4 = \frac{10 \times 10 \times 10 \times 10}{10 \times 10 \times 10 \times 10} = 1$$

$$\text{or } 10^4 \div 10^4 = 1$$

$$10^{4-4} = 10^0.$$

Does $10^0 = 1$? (Yes, by definition.)
The definition of 10^0 is, $10^0 = 1$.

$$10^4 \div 10^7 = \frac{10 \times 10 \times 10 \times 10}{10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10}$$

$$= \frac{1}{10 \times 10 \times 10} = \frac{1}{10^3}$$

or $10^4 \div 10^7 = 10^{-3}$

Does $10^{-3} = \dfrac{1}{10^3}$?

If the subtraction rule is to be used in dividing, it will be necessary to make the definition,

$$\frac{1}{10^3} = 10^{-3},$$

and to extend this to include other examples like

$$\frac{1}{10^1} = 10^{-1}$$

$\dfrac{1}{10^2} = 10^{-2}$, and so on.

This is precisely what is done in defining negative exponents.

Here are illustrations of the definitions of negative and positive whole number and zero exponents as they are used in science:

$$10^5 = 10 \times 10 \times 10 \times 10 \times 10$$

$$10^0 = 1$$

$$10^{-6} = \frac{1}{10 \times 10 \times 10 \times 10 \times 10 \times 10}$$

With these definitions, the addition rule for multiplication and the subtraction rule for division apply. It is exactly these rules that provide the basis for a slide rule. Using a slide rule, multiplication is reduced to addition and division to subtraction.

When you see many powers of ten expressed with exponents, you will discover an interesting relationship between the number of zeros (or decimal places) and the exponents. Examine these examples:

$10^3 = 1000$	$10^{-1} = 0.1$
$10^5 = 100{,}000$	$10^{-2} = 0.01$
$10^8 = 100{,}000{,}000$	$10^{-3} = 0.001$
	$10^{-4} = 0.0001$

Your own formulation of these relationships should assist you in using exponents in writing powers of ten with ease. If you have studied logarithms, you may recall that useful shortcuts were based on these relationships. This should not be surprising, since logarithms are exponents. A slide rule is like a table of logarithms made into a scale. The scale is called a logarithmic scale. As was pointed out before, numbers can be multiplied by adding, and divided by subtracting with the scale.

In order to check yourself at this point, take a piece of paper and pencil and copy the following, replacing the question marks by the appropriate number. (Correct answers are given at the end of this paper.)

Question 1

(a) $10{,}000 \times 100 = 10^? \times 10^? = 10^?$

(b) $10^{-3} \times 10^5 = 10^?$

(c) $0.0001 \times 0.00001 = 10^? \times 10^? = 10^?$

(d) $0.0000001 \times 10{,}000 = 10^? \times 10^? = 10^?$

(e) $10^{-3} \times 10^6 \times 10^0 = 10^?$

(f) $10^{-2} \times 10^2 \times 10^{-6} = 10^?$

WHAT ABOUT NUMBERS LIKE *1,974* OR *93,000,000*?

Thus far, only powers of 10 have been expressed using exponents with the base *10*. But you probably know that each of the numbers,

1,974 and *93,000,000*

can be written as products of a number and a power of *10*. That is,

$1{,}974 = 197.4 \times 10^1$, or, $1{,}974 = 1.974 \times 10^3$

and $93{,}000{,}000 = 93 \times 10^6$ or $9.3 \times 10^?$ (9.3×10^7)

This is true for any rational numbers, including *0* and *0.017* as examples.

$$0 = 0 \times 10^0 \qquad 0.017 = 17 \times \frac{1}{1000} = 17 \times 10^{-3}$$

The speed of light is *30,000,000,000* centimeters per, second, or 3.0×10^{10} centimeters per second. Remember, multiplying a number by 10^{10} is equivalent to multiplying the number by *10,* ten times. Multiplying a number by 10^{-3} is equivalent to dividing the number by *10,* three times.

The mass in grams of an atom of hydrogen is

0.000000000000000000000001673.

Write this number as a product of a number between *1* and *10* and a power of *10.*

($0.000000000000000000000001673 = 1.673 \times 10^{-24}$)

Multiplying a number by 10^{-24} is equivalent to multiplying it by $\frac{1}{10}$ twenty-four times (or dividing it by 10 twenty-four times).

The numbers 3.0×10^{10} and 1.673×10^{-24} are written in *scientific notation.* When a number is written as the product of a number between *1* and *10* and a power of *10*, the number is said to be written in scientific notation. Try writing the following numbers in scientific notation:

Question 2

19,660	(1.966×10^4)
93,000,000	(9.3×10^7)
0.03	(3×10^{-2})

25.4

5280

One hundred eighty-five million

Seventy-five ten-millionths

Why do you suppose it has become customary to write the first factor in scientific notation as a number between *1* and *10*? Why not between *1,000* and *10,000*, for example? The reason is again merely a matter of convenience and ease. Particularly in products and quotients, the decimal points are easier to locate for numbers between *1* and *10*, as you will see in the following consideration.

PRODUCTS OF NUMBERS IN SCIENTIFIC NOTATION

In some of your reading about science, you may find a situation in which numbers written in scientific notation have been multiplied or divided by other numbers in scientific notation. Consider an example in which a product is to be found, and both positive and negative exponents occur in the factors to be multiplied.

For example, suppose you wish to know the sum of the lengths of *32,000,000* cells, each of which has been determined to be *0.000054* centimeter long. In scientific notation, you need to find the product of:

3.2×10^7 (number of cells) and 5.4×10^{-5} (length of each cell).

You could use the decimal forms of the numbers and find

the product, but you can do this mutliplication much more easily in scientific notation. Using the commutative and associative properties of rational numbers, you know that

$3.2 \times 10^7 \times 5.4 \times 10^{-5} = (3.2)(5.4) \times 10^7 \times 10^{-5}$.

What is the product of 3.2 and 5.4? (17.28)

What is the product of 10^7 and 10^{-5}? (10^2)

So the product you are seeking is 17.28×10^2
or 1.728×10^3 or $1{,}728$.

Perhaps you would like to try two examples. Use scientific notation to find the products: Question 3

(a) $(1.2 \times 10^{15}) \times (3.3 \times 10^{-10})$

(b) $(6.0 \times 10^{-3}) \times (8.1 \times 10^{-5})$

COMMENTS ON QUESTIONS

QUESTION 1

(a) $10^4 \times 10^2 = 10^6$

(b) 10^2

(c) $10^{-4} \times 10^{-5} = 10^{-9}$

(d) $10^{-7} \times 10^4 = 10^{-3}$

(e) 10^3

(f) 10^{-6}

2.54×10^1

5.280×10^3

1.85×10^8

7.5×10^{-6}

QUESTION 3

(a) 3.96×10^5

(b) 4.86×10^{-7}

EVALUATION EXAMPLES

1. Express as powers of 10:

   (a) $10{,}000{,}000$
   (b) 0.1
   (c) 0.0000001

2. Express in scientific notation:

   (a) *18,700*
   (b) *210,000,000*
   (c) *0.0000426*

3. Write the following in ordinary decimal notation:

   (a) 10^9
   (b) $10^3 \times 10^4$
   (c) 10^{-5}
   (d) 2.4×10^6
   (e) 9.2×10^{-7}

4. Express the distances in ordinary decimal notation:

   The North Star is 6.39×10^{15} kilometers from the earth.
   The distance of Saturn from the sun is 8.9×10^8 kilometers.

5. Arrange the following numbers in order of size from smallest to largest: 3.7×10^{-2}
   4.1×10^{-4}
   6×10^8
   9.6×10^7
   10^3

COMMENTS ON EVALUATION EXAMPLES

1. (a) 10^7
   (b) 10^{-1}
   (c) 10^{-7}

2. (a) 1.87×10^4
   (b) 2.1×10^8
   (c) 4.26×10^{-5}

3. (a) *1,000,000,000*
   (b) *10,000,000*
   (c) *0.00001*
   (d) *2,400,000*
   (e) *0.00000092*

4. *6,390,000,000,000,000* kilometers
   890,000,000 kilometers

5. 4.1×10^{-4}
   3.7×10^{-2}
   10^3
   9.6×10^7
   6×10^8

PROBABILITY

Although modern probability theory is a complex topic in mathematics, the basic concepts of probability are relatively simple and have many applications in scientific work. Simple probability theory provides the basis for a number of methods used in interpreting data obtained in a wide variety of experimental research studies. Probability theory enables the scientist to evaluate the degree of precision or reliability of his measurements, to make predictions at a specified level of dependability, and to evaluate the risk of error incurred in drawing various conclusions from the results of an experiment.*

To help you better understand the variety of ways in which elementary probability is useful in science, we will discuss *theoretical probability* and *empirical probability*. You will probably not ask children to make the distinction between them, even though the applications of probability in *Science—A Process Approach* include both kinds of situations. This background material goes somewhat beyond the material on probability in *Science—A Process Approach.*

In its classical form, *theoretical probability* was developed in the Eighteenth Century in connection with the study of games of chance. Following is a simple example of this probability in sentence form:

$$\text{Pr (favorable outcome)} = \frac{\text{number of ways favorable outcome can occur}}{\text{number of possible outcomes}}$$

---

*Probability is introduced in two exercises in *Science—A Process Approach.* These are: *A Measure of Chance, Interpreting Data 7, Exercise I,* Part F, and *Drosophila,* a supplementary exercise, Part G.

A *favorable outcome* is any specified result, such as *heads* turning up when a coin is tossed. In tossing a coin, the number of favorable outcomes is one, because *heads* can occur in only one way. The number of possible outcomes is *two* because tossing the coin can turn up either *heads* or *tails.* The probability sentence for getting *heads* from one toss of a coin is thus:

$$\text{Pr}\ (\textit{heads}) = \frac{1}{2}$$

This is an example of theoretical probability because it does not require observation or experimentation. It is an abstract concept pertaining to an imaginary coin which can turn up only *heads* or *tails.* (It cannot stand on edge.) Moreover, we have assumed that *heads* and *tails* are equally likely to occur. Because of such assumptions, this sentence may not be a true statement of the probability of getting *heads* when a certain individual tosses a particular coin because (1) the coin might possibly stand on edge, (2) it might not be balanced so that *heads* and *tails* are equally likely to occur, or (3) there might be a bias in the way it was tossed. Although theoretical probability strictly applies only to artificial situations, it often serves as a model for the interpretation of data.

In many cases, we do not know all of the possible outcomes. Perhaps there may be so many possible outcomes that it would not be easy to list them. It then becomes necessary to estimate probabilities from a sample of data. Because such estimates are based on experimentation and observation, they are called *empirical probabilities.* (Empirical refers to direct experience, while theoretical refers to imagined situations.) Empirical probability sentences are written in a form which clearly indicates that they are based on a sample of data:

$$\text{Pr (favorable outcome)} = \frac{f}{N}$$

In this sentence, N designates the total number of observations in an experiment and f stands for frequency or the number of times a favorable outcome is observed. Thus, to estimate the empirical probability that a baseball player will hit safely when it is his turn at bat, we examine his past record and compute his batting average. The coach's decision about this player will be influenced by this empirical estimate of probability. Empirical probabilities provide a basis for decision or a guide for action in many practical problems of everyday life. For example, insurance rates are decided by using probability and will be considered later in this paper.

Theoretical Probability

COUNTING EVENTS

In its most elementary form, probability is concerned with

a finite set of events that can be counted. Suppose that in a container there are four objects of essentially the same shape, size, mass, and texture, but of four different colors. The objects are white, green, red, and purple. If you draw one of these objects, without looking, it can be assumed that your chance of drawing any one color is equal to your chance of drawing any other color. The objects might be cards, or marbles, or sticks, or any other thing that could be matched except for color.

What is your chance of drawing the red object? Four events might happen:

You might draw the white object
You might draw the green object
You might draw the red object
You might draw the purple object

Only one of these events is favorable; that is, you must draw the red object. What is the chance of your drawing the red object? A measure of this chance is $\frac{1}{4}$ or 0.25.

Sometimes the number of possible events is not easy to count, and in this respect other examples may not seem so simple. Try other examples, still using the same objects and still drawing from the container without looking.

1. What is the probability of drawing the purple object twice if you have two turns? Assume, of course, that you replace the object before the second drawing.

   How many possible events are there? (16)
   How many of these events are favorable? (1)
   What is the probability? ($\frac{1}{16}$)

   Perhaps you did not count 16 possible events. If not, try to list all the possibilities. One way to make the list is as follows in which *w* represents the white object, *g* represents the green object, and so on.

w–w	g–w	r–w	p–w
w–g	g–g	r–g	p–g
w–r	g–r	r–r	p–r
w–p	g–p	r–p	p–p

   The possibilities are listed systematically. You might choose a different system, but even if you do, you should obtain 16 pairs. The event occurring first is listed on the left side each time.
2. What event, considering each of the 16 events, is most likely to occur? (Each event is listed only once, hence each is equally likely to occur; the probability in each case is $\frac{1}{16}$.)

3. You have three draws. What is the probability of drawing objects in this order: white, green, purple? ($\frac{1}{64}$ See Figure 1. The group, $w, g, p,$ is indicated by the rectangle at the top.)

		×	×	×			✓	✓		✓		✓		✓	✓	
First draw	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Second draw	W	W	W	W	G	G	G	G	R	R	R	R	P	P	P	P
Third draw	W	G	R	P	W	G	R	P	W	G	R	P	W	G	R	P

			✓	✓	×		×	×	✓			✓	✓		✓	
First draw	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G	G
Second draw	W	W	W	W	G	G	G	G	R	R	R	R	P	P	P	P
Third draw	W	G	R	P	W	G	R	P	W	G	R	P	W	G	R	P

		✓		✓	✓			✓	×	×		×	✓	✓		
First draw	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Second draw	W	W	W	W	G	G	G	G	R	R	R	R	P	P	P	P
Third draw	W	G	R	P	W	G	R	P	W	G	R	P	W	G	R	P

		✓	✓		✓		✓		✓	✓			×	×	×	
First draw	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Second draw	W	W	W	W	G	G	G	G	R	R	R	R	P	P	P	P
Third draw	W	G	R	P	W	G	R	P	W	G	R	P	W	G	R	P

FIGURE 1

4. What is the probability of drawing objects of three different colors in any order? (Now you have to count in how many outcomes of the 64 possible outcomes you could get three of different colors. To do this, try to group the possible outcomes. Use Figure 1 to help you.)

Possible Outcomes	*Numbers*
All of same color (*www, ggg, rrr,* and *ppp*)	4
First two of one color, third different	$4 \cdot 1 \cdot 3 = 12$
First and last of one color, second different	$4 \cdot 3 \cdot 1 = 12$
First of one color, second of a different color, third same as second	$4 \cdot 3 \cdot 1 = 12$
All three of different colors	$4 \cdot 3 \cdot 2 = 24$
Total possible events	64

P (three of different colors) $= \frac{24}{64}$

If you are not sure why these products give the counts you want, the following discussion will help. The second and last cases are given as examples.

In three draws of one object from a set of four objects of four different colors, in how many ways may an object of the same color be drawn in the first two draws and an object of a different color on the third draw?

There are four colors so the first may be of any four colors.

The first factor is 4.

The second must be of the same color as the first and hence there is only one possibility.

The second factor is 1.

The third must be a different color from the first, and hence there are three possibilities.

The third factor is 3.
$4 \cdot 1 \cdot 3 = 12$

So, there are 12 ways in which an object of the same color could be drawn in the first and second draws followed by an object of a different color on the third draw. The 12 favorable outcomes are marked with an x in Figure 1.

In how many ways may three different colors be drawn? The first may be any of four colors.

The first factor is 4.

The second, being different from the first, may be any of three colors.

The second factor is 3.

The third, being different from the first two, may be either of two remaining colors.

The third factor is 2.
$4 \cdot 3 \cdot 2 = 24$

The 24 favorable outcomes for drawing "all three of different colors" are marked with a check ($\surd$) in Figure 1. Notice that in the list of possible outcomes the sum of the number of outcomes counted is 64. Since you had already determined that the number of possible outcomes is 64, you can be more confident that this count of the separate possible events is correct.

PENNIES AND PROBABILITY

An easy example of probability involves tossing coins. What are the chances that *heads* will turn up if you toss a penny? Would you be surprised if it turned up *heads*? If you tossed the penny twice, would you be surprised if *heads* turned up

both times? Why? How often would you expect two *heads* to turn up? (Once in four tosses, or something similar. See Figure 2.) What is the probability of getting two *heads* when you toss the penny twice? ($\frac{1}{4}$ or 0.25.)

If you tossed the penny three times, and *heads* turned up every time, would you be surprised? Why? Again, count the different ways that three *heads* can turn up. One way to count the possible events is to construct a diagram. (See Figure 3.) The diagram shows that there are $2 \cdot 2 \cdot 2 = 8$ possible outcomes, that these outcomes are all different, and that for each outcome the probability is $\frac{1}{8}$. For example, one outcome is *heads, heads, heads,* and another is *heads, heads, tails.*

What is the probability of getting three *heads* from tossing the penny three times?

[Pr (three *heads*) $= \frac{1}{8}$.]

What is the probability of getting two *heads* from tossing the penny three times?

[Pr (two *heads*) $= \frac{3}{8}$.]

If you are not sure how this answer is obtained, count the outcomes that contain two *heads.* They are:

heads, heads, tails
heads, tails, heads
tails, heads, heads

What different numbers of *heads* could we get from tossing a coin three times? (The possible results are 0, 1, 2, 3.) The probability of these outcomes is $\frac{1}{8}$, $\frac{3}{8}$, $\frac{3}{8}$, and $\frac{1}{8}$ respectively.

A bar diagram can be used to represent the probabilities of various numbers of *heads* that can be obtained from tossing a coin three times. This type of graph, shown in Figure 4, is called a *histogram.* Note that the area of the histogram contains eight 2-centimeter squares. Each square corresponds to one of the possible outcomes, such as *HHT, HTH,* and so on, in which *H* represents *heads* and *T* represents *tails.* These outcomes are grouped to make bars in the histogram according to the number of *heads* contained in each. What part of the total area (8 squares) of the histogram is above each number of *heads*? (See Figure 5.)

The part of the total area which is above each possible number of *heads* is exactly the same as the probability that the number of *heads* will occur. The sum of these probabilities is one. The histogram can be used to represent a probability distribution. It shows how the total probability, which is always equal to one, is distributed in categories corresponding to the various possible outcomes.

First toss	Second toss
heads	heads
heads	tails
tails	heads
tails	tails

FIGURE 2

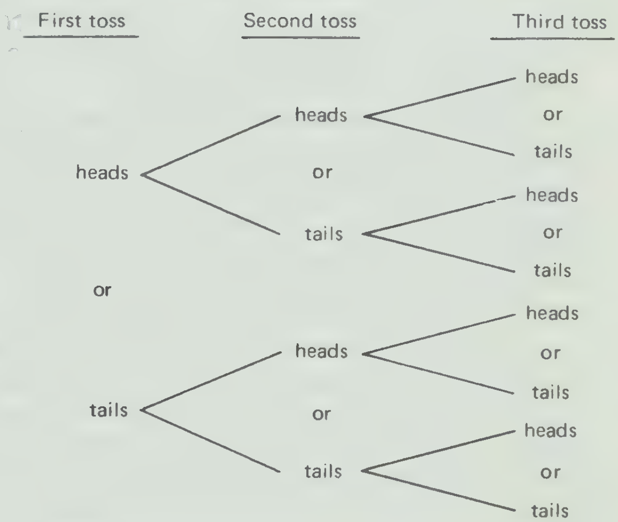


FIGURE 3

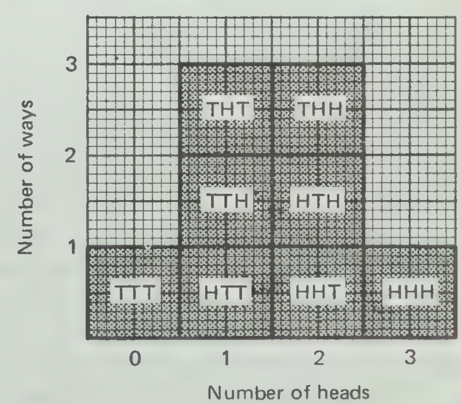


FIGURE 4

It should be noted that, although we have been discussing the probable outcomes of tossing one coin three times, the probable outcomes would be identical if three coins were tossed one time.

Number of heads	Part of area
0	$\frac{1}{8}$
1	$\frac{3}{8}$
2	$\frac{3}{8}$
3	$\frac{1}{8}$

FIGURE 5

THE BINOMIAL DISTRIBUTION

How many *heads* can you get if you toss a single coin? (0 or 1.) We refer to the number of *heads* as a *binomial variable* because it can have only two possible values, zero and one. Other binomial variables are: whether a person says *yes* or does not say *yes* when asked if he likes to play baseball; whether or not the answer to an examination question is correct; or any other observable event which can be classified into one or the other of two mutually exclusive categories.

The possible numbers of *heads* and *tails* for tosses of one, two, and three coins are shown in Figure 6, using *H* and *T* to stand for *heads* and *tails.* Compare Figure 6 with Figure 3.

One coin tossed	1 H	1 T		
Two coins tossed	1 HH	2 HT	1 TT	
Three coins tossed	1 HHH	3 HHT	3 HTT	1 TTT

FIGURE 6

The order of *H* and *T* is not considered in this table. The interest here is only in the number of ways each number of *heads* and *tails* can occur. The groups in the third line correspond to the bars in the histogram in Figure 4.

The famous seventeenth century mathematician, Pascal, discovered a pattern among these numbers which can be used to find the distribution of possible outcomes without listing and counting them. The numerals in the table, shown in Figure 6, are copied in the first three lines of Figure 7, and lines are added for four coins, five coins, and so on. The array of numbers in Figure 7 represents the first seven lines in *Pascal's triangle.*

One coin tossed							1		1						
Two coins tossed						1		2		1					
Three coins tossed					1		3		3		1				
Four coins tossed				1		4		6		4		1			
Five coins tossed			1		5		10		10		5		1		
Six coins tossed		1		6		15		20		15		6		1	
Seven coins tossed	1		7		21		35		35		21		7		1

FIGURE 7

What is the pattern in Figure 7 that can be used to write the next line? (The key to the arrangement of numbers in Pascal's triangle is that, from the second row on, each number in a row is the sum of the two numbers at either side of it in the row immediately above. Empty spaces are considered to be zeros.) Note that the sum of the possible outcomes for n coins will always be 2^n. For example, for $n = 5$,
$1 + 5 + 10 + 10 + 5 + 1 = 32$ or 2^5, that is, $2 \cdot 2 \cdot 2 \cdot 2 \cdot 2$.

For example, suppose four pennies are shaken in a cup and dumped onto a table. What are the possible values of the variable, the number of *heads*? (0, 1, 2, 3, 4. That is, there might be no *heads* showing, or one *head* and three *tails,* and so on.) How many possible outcomes are there? ($2^4 = 16$.) How many ways can each possible number of *heads* occur when four pennies are dropped on the table? (Two ways are easy to see. There is only one way to have zero *heads.* That is when all four pennies show *tails.* And likewise there is only one way for the pennies to show four *heads.* So it is easy to fill in the first and last lines of Figure 8. You can use Pascal's

Number of heads	Number of ways
4	1
3	4
2	6
1	4
0	1

FIGURE 8

triangle to find the number of ways four pennies could show 1, 2, or 3 heads when they are tossed. The numbers in the fourth line of Figure 7 are 1, 4, 6, 4, and 1, and these are the numbers that are in the second column of Figure 8.)

In order to make Figure 8 more clear, consider the line for three heads. Suppose you marked the four coins *A, B, C,* and *D*, and then put them in the cup, shook the cup, and dumped it. Figure 9 shows the four ways the coins could fall on the table with three *heads* showing.

	Coin *A*	Coin *B*	Coin *C*	Coin *D*
First way	H	H	H	T
Second way	H	H	T	H
Third way	H	T	H	H
Fourth way	T	H	H	H

FIGURE 9

What is the theoretical probability of each possible number of *heads* in Figure 8? (Divide each of the number of ways by the total number of possible outcomes.

Example: Pr [two *heads*] = $\frac{6}{16}$ in tossing 4 coins.)

It would be instructive to do two things now before continuing your study. First, construct a histogram showing the number of ways in which 0, 1, 2, 3, 4, 5, 6, and 7 *heads* may be obtained when 7 coins are tossed. Recall Figure 4, and use the line for 7 coins in Figure 7. Then, plot a *frequency polygon* showing the numbers of *heads* in 10 tosses of a coin. To do the latter, you will need first to extend Pascal's triangle to 10 coins. Then, instead of constructing a bar to show the number of *heads* as you did when you make the histogram, just mark the point above each number of *heads* that corresponds to the number of ways the *heads* can be obtained. Then connect the points. The resulting curve is a frequency polygon. (See Figure 10.)

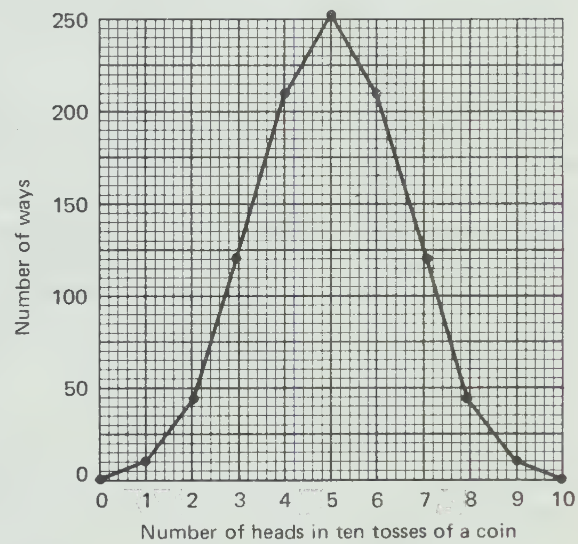


FIGURE 10

Examination of the two histograms (Figure 4 and the one you constructed) and the frequency polygon leads to inferences about characteristics of the histograms or polygons as the number of coins gets larger. For example, the polygon gets higher in the center as the number of coins tossed gets larger. There are also more bars in the histogram and more sides in the polygon. How would the frequency polygon look if it represented the expected frequencies for the numbers of *heads* we might get in tossing 50 coins? 100 coins?

If we tossed a huge number of coins, there would be many possible outcomes. There would be many possible numbers of *heads.* There would be many sides to the frequency polygon, and the graph would look like a smooth curve. Its silhouette looks like a bell, and many people call it a bell-shaped curve. It is also called a *normal distribution*, or a *binomial distribution,* and it is the curve to which reference is made when one says, "He grades on the curve."

Examples of measurements which are *normally distributed* are people's heights, weights, and ability to do mathematics. Would you expect to find a normal distribution of the weights of the leaves on a very large tree?

Empirical Probability

Hold a paper clip at arm's length. If you drop the paper clip, what is the probability that it will come to rest on a crack in the floor? (If the floor does not have cracks between boards or between tiles, you can use a piece of heavy wrapping paper—about 80 x 80 centimeters—which has been ruled into 4-centimeter squares.) In this situation, it is not possible to count all of the ways the paper clip can fall on a crack or not on a crack. How might an estimate of the probability that the paper clip will land on a crack be obtained? When the number of possible outcomes is unknown, or too large to be counted, probability can be estimated from empirical data. The empirical probability that an event A will happen is:

$$\Pr(A) = \frac{f_A}{N}$$

A favorable outcome is any way that A might possibly occur. For instance, if any part of the paper clip touches a crack we will count it as an occurrence of A. f_A means the frequency, or the number of times A has been observed. N means the total number of observations in an experiment.

You may wish to drop the paper clip many times and record the data. Suppose your data for 300 trials are like this:

Fell on crack	96
Did not fall on crack	204
Total trials	300

(Data will vary according to the size of the paper clip and the spacing of the lines.)

Using these hypothetical data, what is the empirical probability that the clip will fall on a crack? ($\frac{96}{300}$). You would expect the paper clip to fall on a crack a little more than three times in 10 trials.

Another simple application of empirical probability can be made to quality control. Suppose a manufacturer of metersticks finds that out of 1,000 metersticks selected at random from a much larger number, six are defective in some respect. He may conclude that the probability of a meterstick being defective is:

$$\frac{6}{1{,}000} = 0.006$$

He might be satisfied with the quality of his product or he might try to determine what produces the defective metersticks. After appropriate changes, he may take another sample to see if there has been an improvement. Think about questions like the following.

1. After the manufacturer has made certain changes, he takes another sample of 1,000 metersticks and finds

four of them to be defective. What is the probability that his company will now produce a defective meterstick? (0.004) Is the quality of the metersticks improved? (Yes, at least according to the samples.)

2. What is the probability that a meterstick chosen at random from his stack will be nondefective (a) before the change and (b) after the change? (before the change, 0.994; after the change, 0.996).
3. If he fills an order for 36 metersticks from the stack produced after the change, how many will he expect to be defective? (36 x 0.004 = 0.144, none) How many will he expect to be defective in an order for 2,500 metersticks? (2,500 x 0.004 = 10)
4. Suppose a merchant purchases 1,500 of the metersticks for resale at a price of 35 cents each. He pays $300 for the wholesale lot of 1,500. If the expectation is that 0.004 of the metersticks are defective and cannot be sold, what is the merchant's expected profit? (The merchant can expect 1,500 x 0.004 = 6 to be defective. He can sell 1,494 @ 35 cents. 1,494 x 3.5 = 522.90. His profit will be $522.90–300, or $222.90.)

In everyday affairs, many other applications of probability are made in which the probability ratio is computed from empirical data based on a sample of all possible outcomes. For example, insurance rates are based on empirical probability. Suppose out of 10,000 trips by automobile between Washington and Baltimore there are 11 accidents. In 8 of the accidents, the drivers were under 25 years of age, and in the others the drivers were over 25. Why would insurance companies be justified in charging more to insure a driver under 25 than a driver over 25? (The probability, based on these data, that a driver under 25 will have an accident is $\frac{8}{10,000}$ or 0.0008, while that for a driver over 25 is 0.0003.)

How do you know you have the correct value for an empirical probability? Empirical probabilities are never precisely known because they are based on the results from a sample of observations. Samples differ from each other as the result of unknown factors. We call this *chance variation.* The amount of chance variation from sample to sample becomes less as the samples are made larger.

THE CELL

By simple application of their reasoning powers, some of the earliest Greek philosophers deduced the existence of the atom, which provides a common basic structure for all matter. Until the invention of the microscope in the mid-1600's, however, no one so much as suspected that a second kind of common structure might exist in living things. It seems almost paradoxical that life forms as different as an elephant and a butterfly could be made up of the same basic unit, but they are. That unit is the cell. Although the realization that all living things have a common cellular structure was a century and a half in developing, we think of it now as a surprising discovery. Students can share some of that surprise by seeing cells for themselves.

The word *cell* is well known and has a number of different uses with which children are familiar. Some of these are *prison cell, dry cell, air cell, fuel cell, animal cell,* and *plant cell.* All find their origin in the Latin word *cella,* meaning a small room or hut, and all refer to smallish units that (1) have distinct boundary structures, (2) are repeated many times in nearly identical form, and (3) contain important objects or materials.

In Parts F and G, children use a microscope to study the cells of some living things and to compare those cells and their parts with nonliving materials such as grains of sand or salt.

INSIDE PLANT AND ANIMAL CELLS

When you look through a microscope at a thin slice of material from a many-celled organism, you see what seem to be many little boxes pressed closely together. In plants, these are often rectangles. In animals, the figures are usually many-sided. However, it is not really correct to think of cells as

boxes. The lines which seem to form boxes are merely the boundaries between the cells. In many cases, those lines are not living structures at all. It is wise to skip rapidly beyond this first impression of boxes and think, instead, of cells as the chunks of material *within* the lines. The material is a sticky substance that is constantly doing things to itself: stretching, straining, generating heat, changing from thick liquid to flabby gelatin, building more sticky stuff from dissolved materials taken in from outside, and splitting into smaller cells that grow and split and grow again. It is easy to think of a frog, a worm, or even a human being as a neatly organized pile of little boxes. But it is much more fascinating to view those living organisms as marvelously coordinated sets of processes, each of which originates as activities that we can sometimes actually see within these tiny units.

Normally, we see cells under the microscope as if these activities were not constantly going on. In fact, we usually use materials that are dead to demonstrate the cellular structure of living things. This is true of the thin sheets of onion peel and bits of skin in the scrapings from inside one's cheek, used in the easiest demonstrations of cellular structure; it is true too of the carefully stained and preserved tissues on prepared microscope slides.

In good tissue preparations, the contents of the cell are often as conspicuous as the walls or membranes which surround them. Preservation and staining make it possible to see things inside the cell that would ordinarily be translucent. After staining, the most conspicuous structure is usually the *nucleus,** a large, often darkly stained, round body that typically lies near the center of the cell. Sometimes, one or more especially dark spots, each called a *nucleolus,*** can be distinguished inside the nucleus.

Surrounding the nucleus is the main mass of the cell, the *cytoplasm.* In the simplest of cells, the cytoplasm is a homogeneous, faintly granular, sticky fluid, but in most cells, clearly differentiated particles, fibers, or spaces can be seen. Surrounding the cytoplasm is an exceedingly thin covering called the *cell membrane.* This is so thin that it often behaves as if it were just the exposed surface of the cytoplasm, but it is now known to be structurally distinct. All three cell areas, nucleus, cytoplasm, and cell membrane, are actively involved in life processes and hence are included in the single term, *protoplasm,* which is the living material of the cell.

Cells of the common water weed, *Elodea,* provide an easy

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*Practice pronouncing this as "new'-klee-us." It is one of the most badly mispronounced words in all of science.

**New-klee'-oh-lus; plural, necleoli—new-klee'-oh-lie.

microscopic demonstration of typical food-producing cells of plants. (Tear a very thin sheet of tissue from the surface of a leaf of *Elodea,* and mount it in a drop of water under a cover-slip on the microscope slide, using the lowest power of magnification and the minimum amount of light.) Sturdy, non-living cell walls make the *little-boxes* interpretation of cellular structure a tempting one. These walls are made up largely of cellulose secreted by the living cells. The cell walls are conspicuous because of the many green bodies called *chloroplasts* contained in their cytoplasm. The chloroplasts serve the cell as centers of photosynthetic activity. They help us to interpret what we see in the cell by revealing (1) that most of the protoplasm of these cells lies out close to the cell walls, (2) that the center of the cell is occupied by a large cratery space called a *vacuole,* and (3) that semi-fluid cytoplasm may sometimes flow actively about within the cell. The latter motion is visible only in very fresh and healthy preparations; it is not typical of all cells. Careful shifting of the light is necessary to reveal the nucleus, which is usually visible in faint outline only. It is normally pressed against one wall and is many times the size of the chloroplasts. Living cells seldom reveal more detail than this under classroom conditions.

It is always interesting to see the specialized forms of cells in other tissues. (A *tissue* is a mass of similar cells and intercellular material that serves some special role in the life of a multicellular organism.) It is fun, too, to watch the movements of the single-celled animals and plants that are present in great numbers in densely green pond and puddle water. Also, a tiny bit of dirt mixed with dead field-grass and soaked for two weeks will provide a rich culture, containing microscopic monsters that will keep students talking for days. Rapid, jerky motions of these micro-organisms can be slowed by mixing the drop of pond or culture water with a little bit of methyl cellulose. Demonstration of the structure and motion of *Amoeba,* which can be purchased from a biological supply house, can be especially instructive. Its structure and motion provide a reference point for both scientific and literary works. Tissues on the other hand, ordinarily display little activity and are more useful in demonstrating diversity and division of labor.

CELL FUNCTIONS

Functionally, the cell is the smallest unit that is capable of maintaining the complete energy system of life. This system includes activity ranging from the very simplest intake of food to the very complex action of producing whole new units, which can then repeat these processes. Thus, we might say that the system uses energy to get energy to get more energy.

The system includes many very different processes: some have to do with the necessary minute-to-minute chemical activities (metabolism) of the cells; some enable the cells and organisms to respond advantageously to conditions in their environment; some contribute to growth and reproduction of the system. Metabolism, responsiveness, and reproduction are sometimes regarded as the defining functional characteristics of life. The potential to carry out the many processes contributing to each of these defining characteristics exists in every living cell.

In general, metabolism is carried out by the cytoplasm. General control of metabolism is maintained by the nucleus (through the nucleolus) which also has the much more demanding job of directing and carrying out most of the process of cell division. The cell membrane manages the exchange of materials and, through electro-chemical activities on its surface, triggers most of the more rapid responses of the cell.

Many cells actually do carry out all of the necessary processes of life and are able to exist as single-celled organisms. For example, protozoa, yeasts, bacteria, and many algae are single-celled organisms. It is not unusual, however, for some cells to be specialized in favor of one or a few abilities at the expense of others. In a multicellular organism, different patterns of specialization can be teamed up to carry out all of the necessary living functions. Cells in such an organism vary greatly in form, but in some degree, they all possess the full set of life functions.

CELL DIVISION

The most complex of cell functions is called *cell replication.* In many single-celled organisms, this is all there is to reproduction. In multicellular organisms, it is central to both reproduction and growth. Two separate actions are involved in the replication of a cell: (1) *duplication* in the nucleus of the long threads of hereditary material called *deoxyribonucleic acid,* or *DNA,* and (2) *division* of the whole cell into two smaller cells. Plants and animals differ slightly in the details of cell division, but on the whole, the process is remarkably similar in the two groups of organisms.

CELLS IN BIOLOGICAL RESEARCH

The history of science is rich with the accounts of man's attempt to understand life. Much of the attention in this quest has focused on the cell, starting with Robert Hooke's first description of cellular structure in cork in 1665. Schleiden's and Schwann's separate but almost simultaneous expressions of cell theory followed a century and a half later. As initially presented, this amounted to nothing more than the simple

statement that all living things are composed of cells. However, constant reexamination of the necessary implications of this idea has brought an expanded interpretation that places cell theory at the very heart of much of modern biology. Some necessary additions are as follows: It is the set of dynamic processes that takes place within the cell that is most important in making cells the fundamental unit of life; new life (as we know it today) comes only with the formation of new cells from older ones; the characteristics of living things are the aggregate of characteristics of the cells.

New discoveries about cells are always presented quite tentatively, for they consistently pose more questions than they answer. Answers to these questions often force revision of the earlier conclusions. Much of the current work in biology is concerned with the biochemical nature of living materials. So many exciting discoveries are reported each month, it is easy to forget that each is simply a step in strengthening our understanding of the concept of the cell. In a sense, the excitement of the discovery of cells is recreated each time a new idea is confirmed and new vistas and new questions come into being. A child's first association of the object with the idea, of the living cell with the functions it represents, can yield some of that same excitement.

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THE MICROSCOPE

The general background information given here about microscopes and their use is applicable to a wide variety of instruments and should help you to capitalize on your pupils' natural interests.

WHAT IS A MICROSCOPE?

Anything that enlarges an image of a small object that is close to the observer is a microscope. This includes instruments as simple as a hand lens (magnifying glass) and as complex as an electron microscope. In the case of the typical classroom microscope, the image is transmitted directly to the retina of the eye. The image can also be projected onto a screen or photographic plate. A microprojector is a microscope that is rigged to throw the image onto a screen; an electron microscope records the image on a photographic plate. The magnifying power of these different kinds of microscopes ranges from low (magnified a few times, or x) for a hand lens, to very high (well over a million x) for an electron microscope.

We shall confine our attention to three types of optical instruments, the *simple* microscope, the *compound* microscope, and the *microprojector.* Common to all these are a *light source,* a *stage* for holding the specimen, and a *lens* or lens system for magnification. Two possible arrangements of these three elements are shown in Figures 1 and 2. In Figure 1, the specimen to be studied is placed on an opaque stage and the light source illumines the specimen from above. The viewer then observes the specimen by the light reflected from it. In Figure 2, the arrangement is such that the specimen is illumined by light passing through it, and there is a hole in the stage over which the mounted specimen is laid.

THE SIMPLE MICROSCOPE

This term applies to either instrument shown in Figures 1 and 2. Usually the magnification is low. (Most reading glasses magnify only 2.5 or 3 times.) However, it is possible to design the lens to obtain higher powers by carefully shaping the curvature of the glass and by cementing together lenses made of different kinds of glass. The microscope is still simple if only one image of the specimen is formed by the lens and it is this image which is observed.

The first great microbiologist was Anton von Leeuwenhoeck* (1632–1723). He was a Dutch merchant whose hobby was grinding lenses and using them to look at things. He became so expert at shaping and designing lenses that he obtained magnifications ranging from *40x* to *275x.* Once he made a usable lens from a single grain of sand! Leeuwenhoeck devised mechanical methods for adjusting both lens and specimen heights and distances. He even specially designed a way to hold minute glass vials or capillary tubes so that he could observe liquids at close range. Not only did he design and construct the instruments, but he also recorded and described what he saw with his simple microscopes. The science of bacteriology began when he became the first man to observe bacteria that he found in material taken from between his teeth. His work is described in *The Unseen World* by René Dubos, published by the Rockefeller Institute Press in New York.

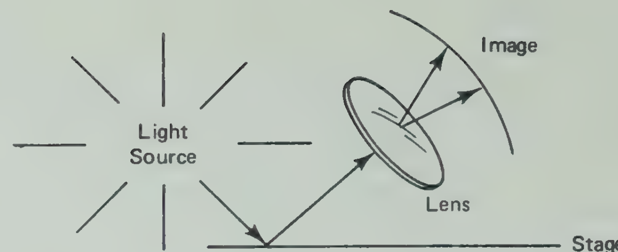

FIGURE 1

THE COMPOUND MICROSCOPE

If a second lens is placed above the image plane in the simple microscope, additional magnification can be achieved. (See Figure 3.) The lower lens then becomes the objective and the upper one, the eyepiece. The eyepiece in this instrument forms an image of a part of the image formed by the objective. The total magnification is the *product* of the separate steps. Thus, a *10x* objective with a *15x* eyepiece yields a magnification of *150x*.

Theoretically, one could continue to add lenses to obtain even higher magnifications. However, note that in the suggested microscope, if the first lens magnifies ten times, the light passing through a 1-millimeter circle is spread across a circle 10 millimeters wide. The 1-millimeter circle that the second lens magnifies is then spread across a circle 15 millimeters wide. Only a very small fraction of the original light is observed in the magnified image. As a result, a very bright light source is required at high magnification.**

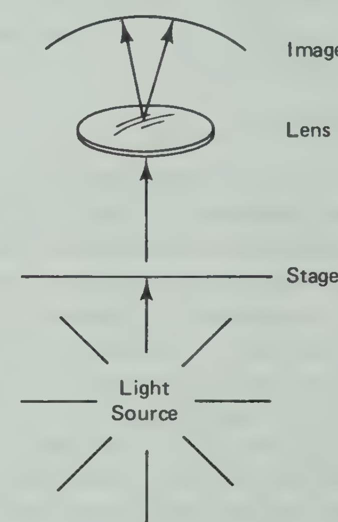

FIGURE 2

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*Pronounced Lee-oo-ven-hoo-eek

The practical limit to magnification with a compound microscope is about *500x* unless other special adaptations are made. Various ingenious devices (like filling the very small space between the objective lens and the specimen with oil, or treating the light in special ways) have been employed to increase magnifications with this instrument to about *2,000x*, but it requires delicate expertness to achieve this.

MICROPROJECTORS

In converting a microscope to a microprojector, one replaces the retina of the eye with a screen. Magnification now depends on both the characteristics of the lenses and the distance to the screen. But, when magnification is increased, problems arise. For one thing, a much more powerful light source must be used because the image is spread over a much larger surface; only a tiny proportion of the light leaving the eyepiece now reaches the eyes of the viewer. But, using a more powerful light source means that slides can become overheated rapidly unless special heat-absorbing filters are added. The chain of problems continues from there. Microprojection is useful to show important details and to gain the advantage of class discussion. However, when using a microprojector, be sure that slides do not overheat, that the room is sufficiently dark, and that students can view the image almost straight on.

VARIATIONS

Just as there are variations in automobiles and refrigerators, there are also variations in the types and styles of microscopes. Binocular eye pieces add a bit of a third dimension; inclined tubes decrease backache; substage condensers and built-in light greatly improve the intensity and quality of light reaching the slide; mechanical stages eliminate some problems of hands that seem to be all thumbs; and rotating nosepieces and zoom lenses provide a wide range of magnifications. While such refinements make it easier to use the instrument, they do not materially increase its magnifying power and therefore represent less important improvements to microscopy than such techniques as oil immersion.

TIPS ON MICROSCOPE USE

The magnifications we have been talking about will only be achieved satisfactorily if the specimen mountings and the sur-

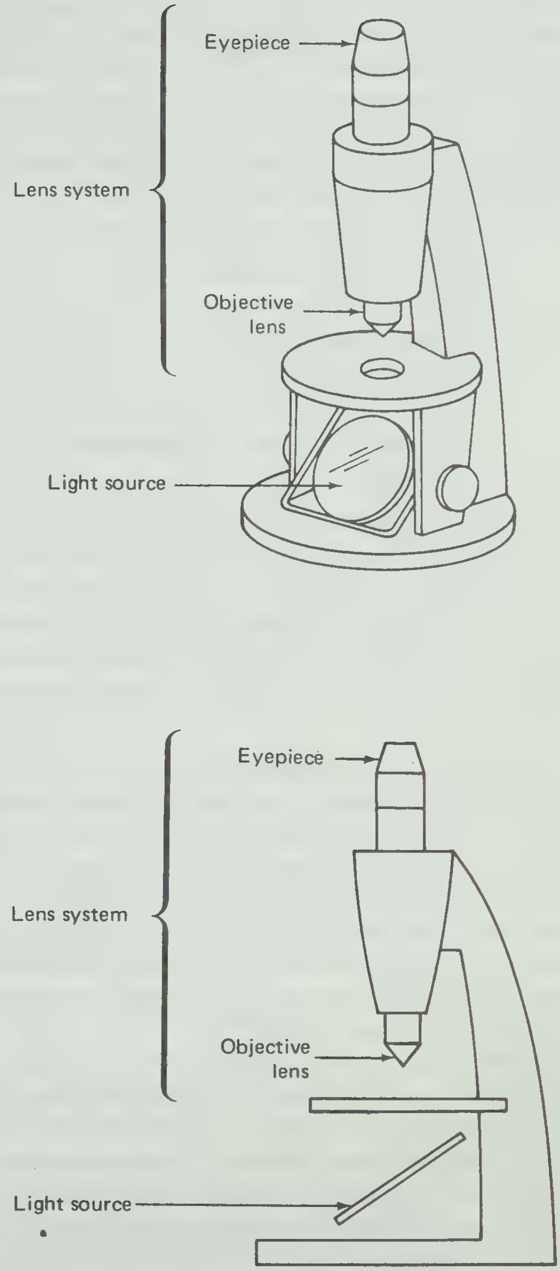

FIGURE 3

**You might find it interesting to calculate the intensity of the light per unit of area in a compound microscope using two *10x* lenses, assuming that light rays enter in a parallel beam and no light is lost at any point. (Use the Bausch and Lomb Company's pamphlet, *The Theory of the Microscope,* for help.)

faces of the optical parts of the microscope are clean. Set a good example by keeping all optical instruments (projectors as well as microscopes and hand lenses) carefully covered when they are not in use. Handle all slides, lenses, and mirrors, as well as photographs and pictures, at the edges only. Point out that professionals and experts take these same precautions.

When you uncover the microscope, remind the class that there are three good ways to ruin it:

1. If you turn it upside down, a lens may fall out and break or be chipped
2. If you clean the lenses or mirrors clumsily, you may scratch the glass
3. If you knock it off the table onto the floor, more than the glass parts may be damaged

Equally disastrous can be damage to slides. Commercially prepared slides may be expensive and difficult to obtain. Any slide can be broken if it is dropped, or if it is crushed by the microscope objective being focused down instead of up. With these possible disasters in mind, develop rules for the proper care and operation of the microscope. The rules might come under four headings: mounting, surfaces, light, and first steps.

MOUNTING. Place the object to be viewed on a clean slide, add a drop of water, and place a clean cover slip carefully on top of the water. Lower one edge of the cover slip to the slide first, and then ease the rest of it down. This will force any air bubbles out from around the specimen. You will quickly discover that the object must be smaller and thinner than you think you can handle in order for you to see the details. When the slide is ready, put it aside and make sure that the microscope is ready too.

SURFACES. All of the surfaces through which the light will pass must be clean. This includes the slide and cover slip and is especially important for the outside surfaces of the objective and eyepiece lenses. If these lenses are dirty, you will not see the dirt itself through the microscope because it is not in the focal plane. You will see only fog or fuzz. Dried water spots, and grease from fingers, the tip of the nose, or eyelashes are common culprits. These slight residues catch hard little bits of dirt or dust and this can scratch. Use lens cleaner (xylol) and clean lens tissue (a specially prepared paper) and wipe gently and delicately. Lens tissues must be kept in covered boxes so that they do not themselves add dirt which will scratch.

LIGHT. Slip the prepared slide into place on the stage and turn on the illumination. If the microscope has a mirror rather than a built-in light source, do not use direct sunlight. (This

is a matter both of comfort and safety and of protecting the specimen from overheating.) As you view the slide from the side of the instrument, you should see a small round dot of light directly below the objective. The light should not be wider than the objective. Then look through the eyepiece to see if the light is spread evenly over the field of view. Make any adjustment necessary to have an evenly lit field. The light must not be bright. Cut it back until you would describe it as almost dim. When you are satisfied that the light is suitable, look away from the eyepiece. You are ready for the *first steps* of observing.

FIRST STEPS. Lean around to the side of the microscope and do three things:

1. Make sure that you are starting with the *lowest magnification* the instrument has
2. Check that the specimen is in just the right place in the circle of light
3. Still leaning around the side, use the focusing screw to *run the objective down* as far as it will go until it *almost but not quite touches the cover slip.* Remind yourself that when you are observing, you always *focus by moving up from the slide, never down*

Now you are ready to look at the specimen through the microscope. Turn the focusing screw slowly to raise the objective. The image will come briefly into focus, and you will probably go past the best position. If you do pass the focal level, go back to step 3 of *First Steps.*

Finally, try these refinements to enhance your skill with the instrument.

1. When you find something under low power that you would like to look at with higher magnification (if your instrument will allow this) adjust the position of the slide on the stage so that the area you want to examine is in the center of the field of view. Then, when you rotate the objective to bring the higher power lens into position, the desired area should still be in the field of view
2. Adjust the lighting from time to time to see if more details come into view
3. With powers of *40x* or more, use the fine-adjustment focusing screw, if you have one, to change the location of the focal plane by small amounts. Your specimen will be thicker than the depth of the field and the fine structure will become clear only if you do this sort of constant fiddling

An infinite variety of materials lend themselves to micro-

scopic study if they are properly prepared for viewing. Try to spend some time practicing the techniques of hand-sectioning, mounting, and staining. Hand-sectioning involves making very thin slices of plant or animal material with a single-edged razor blade. Some stains which can be used easily on live or recently killed tissues are Wright's stain (methylene blue and eosin), aniline blue, alizarin red, methyl green, and ordinary tincture of iodine. If your students are interested, you might let them prepare slides.

REFERENCES

Your school or local library probably has several of the excellent books on using the microscope which are usable by students. The American Optical Company, Buffalo, New York, and Bausch and Lomb, Inc., Rochester, New York, are manufacturers of microscopes. Both distribute leaflets about microscopes which are designed primarily for adult use.

Among the many books for student (S) or teacher (T), or for both student and teacher (ST), that you might add to your classroom collection are the following.

ST Anderson, M.D. *Through the Microscope: Man Looks at an Unseen World.* Garden City, New York: The Natural History Press, 1965.

ST Beeler, N.F., and Branley, F.M. *Experiments with a Microscope.* New York, N.Y.: Thomas Y. Crowell Co., 1957.

ST Beiser, A. *Guide to the Microscope.* New York, N.Y.: E.P. Dutton and Co., Inc., 1957.

T Corrington, J.D. *Exploring with Your Microscope.* New York, N.Y.: McGraw Hill Book Co., Inc., 1957.

T Cosgrove, M. *Strange Worlds Under a Microscope.* New York, N.Y.: Dodd, Mead and Co., 1962.

ST Cosgrove, M. *Wonders Under a Microscope.* New York, N.Y.: Dodd, Mead and Co., 1959.

T Cosslett, V.E. *Modern Microscopy: Or Seeing the Very Small.* Ithaca, N.Y.: Cornell University Press, 1966.

ST Dubos, R. *The Unseen World.* New York, N.Y.: The Rockefeller Institute Press, 1962.

ST Headstrom, R. *Adventures with a Microscope.* New York N.Y.: J.B. Lippincott Co., 1941.

ST Johnson, G., and Bleifield, M. *Hunting with the Microscope.* New York, N.Y.: Sentinel Book Publishers, Inc., 1963.

T Jones, R.M. *Basic Microscope Techniques.* Chicago, Ill.: The University of Chicago Press, 1966.

S Pyszkowski, I.S. *The Microscope and a Hidden World to Explore.* Racine, Wisconsin: Whiteman Publishing Co., 1963.

LEARNING ABOUT LEARNING

Behavioral Science in the Elementary School

In *Science—A Process Approach,* there are four regular exercises and one reading exercise concerned with learning. The exercises are: *Guinea Pigs in a Maze, Interpreting Data 1, Exercise d,* Part E; *The Effect of Practice on Memorization, Controlling Variables 6, Exercise e,* Part F; *Forgetting and Relearning, Controlling Variables 8, Exercise j,* Part F; *The Teacher Cat, Reading Exercise,* Part G; *Learning Codes, Experimenting 7, Exercise l,* Part G. In addition, there are several other exercises that are also based in the behavioral sciences.

In general, elementary and secondary school science curricula have been derived from questions and content in the natural sciences. The inclusion of exercises from the behavioral sciences in an elementary school science program is a genuine innovation. Teachers, and even children in their classes, have come to think of any content not clearly from the natural sciences as out of place in a science program. In the feedback on exercises in the five years of tryout and development of this program, tryout teachers frequently noted in their reports on the behavioral science and mathematics exercises that the children said, "These exercises are all right, but they are *not* science." Those responsible for the development of *Science—A Process Approach* consider this an erroneous and unfortunate point of view. The teaching of the program should contribute to correcting it.

Children acquire competence in the processes of science by using them in a variety of situations. They measure and infer while studying forces or tracks and traces of animals. They formulate hypotheses and interpret data while investigating the effect of temperature on fermentation. The processes of science are as important in the study of behavior as they are

in studies of cells or semipermeable membranes. As children learn about learning, they become more proficient in the processes of science, and they become thoroughly familiar with the fact that the investigation of animal or human behavior is science.

This background paper provides a brief synopsis of the way psychologists view learning and instinct. As a teacher, you will find this essay of much interest, even though it is not applied directly in the learning exercises of the program.

Learning and Instinct

Suppose you had the ability to build a robot that would exactly mimic the behavior of a human. You would need to make a tough decision at the outset. Should you design the robot so it responds automatically to the world? Or should you construct it so it will register the results of its behavior in order to give preference later to those behaviors that led to desirable outcomes? You would, of course, be deciding whether to make the robot act by instinct or by what is learned.

INSTINCT

As a child grows older, his behaviors change. A given change may occur because of specific experiences. In this case, we say that the child has learned something. On the other hand, the change may be due to internal growth having nothing to do with experience; here we say that maturation, a modern term for instinctual changes that occur over time, is responsible for the alteration in behavior.

Nowadays, humans like to believe that they learn from experiences, rather than act by instinct. Most people agreed with this until Darwin, arguing that the human being was a highly developed animal, rather than an entirely different kind of being, insisted that humans as well as animals had instincts. The tide of opinion turned, and for half a century learned men drew up long lists of human instincts. In the early part of this century, however, another swing of the tide set in, and instincts were again thought to be confined to lower organisms. In more recent times, so-called instinctive behavior has undergone considerable sophisticated examination that usually has demonstrated that behaviors our ancestors thought were the outcome of simple instincts are instead complex, often containing components that are learned.

LEARNING

Actually, no matter how strongly a person feels about animal behavior being the result of instinct, he cheerfully acknowledges many instances of animal learning. He may have

taught his dog to play dead, shake hands, or roll over; he knows there are schools for teaching dogs more useful behaviors. At the zoo, he will not suggest that the seal balanced balls on his nose because he has an instinct to do so, nor will he claim that the circus bear rides a motorcycle because nature intended him to. Certainly these are behaviors which were learned; *the animal did not exhibit these behaviors before the instruction by the animal trainer.*

If a person alters his opinion about the generality of instinctive behavior in animals to allow a considerable role for learning, his position comes nearer to that taken by the majority of modern animal psychologists. To them, it seems clear that certain animal behaviors are rigidly instinctual, some are entirely learned, and others are a compound of instinctive and learned features.

The simplest kind of learning is called *conditioning.* Psychologists who study this kind of learning usually employ animals as subjects, but humans also can be conditioned. In humans, conditioning can take place without awareness. The subject may not know he is learning something, and thinking or reasoning are absent.

A more complex kind of learning involves *trial-and-error*. Here, the human or animal tries several behaviors and tends with experience to favor those that lead to desirable results. The favorite device for studying trial-and-error learning is the maze. Initially a human diversion, as in the complicated hedge mazes found in formal gardens, the maze has been reduced to combinations of T-units in the laboratory. In such settings, humans learn the correct paths at about the same rate as rats. The superior power of the human mind does not really appear until the material to be learned tends to become abstract. Thus, an alternation maze, one in which the subject moves repeatedly over the same pathways but must take them in some prescribed order, such as *left, right, right,* is virtually impossible for rats; however, once humans are old enough to recognize relative directions alternation mazes present little problem.

Human superiority show, itself in situations where the use of language is helpful in mastering the material to be learned; however, when language is heavily involved in the task, the psychologist may not always classify it as one of learning. He may prefer to invoke the notion of problem-solving, reasoning, or thinking. The line separating these characteristically human activities from ordinary learning is vague, and some ability to reason, or at least to put together separate experiences to solve a novel problem, has been claimed for animals as low on the scale of development as the rat. The great apes, of course, often carry out acts that observers would identify as requiring thinking or reasoning if performed by humans.

Even lower animals are able to mimic human performances; they substitute trial-and-error and conditioning procedures for higher kinds of learning. Such animal behaviors are *shaped,* that is, taught by the techniques of *gradual approximation* used by animal trainers. Whether or not the animal "understands" what he is doing is of no consequence to the trainer. However, some psychologists argue that variations of the approximation method can be used to teach humans particular complex performances and promote understanding at the same time. Thus, we have certain types of teaching machines using programmed instruction to operate according to training principles first applied to animals.

IMPRINTING

The most shattering blow to a clear distinction between instinct and learning has come from studies of *imprinting* in animals. In nature, ducks prefer ducks and geese prefer geese as mates and associates. Since these preferences seem universal within a given species, most of us would be inclined to attribute them to instinct. It now seems that such preferences may depend upon experience at certain limited and critical periods of life, usually soon after an animal is born. Tampering with this experience by imprinting other experience, so that the animal does not come into contact with members of its own species during the critical period, may produce relatively permanent deviations from the normal social behavior of the species. For example, if newly hatched ducklings are exposed to a moving object, either animate or inanimate, they will from that time on follow that object rather than an adult female duck. At the same time, we should keep in mind that not all animals are known to imprint on their early associates; the European Cuckoo and the American cowbird, for example, lay their eggs in other species' nests but mate their own kind as adults.

INVESTIGATING BEHAVIOR

Perhaps the basic danger in classifying behavior on the basis of instinct or learning is that it encourages armchair speculation rather than careful controlled scientific study. Anyone can say that a particular behavior is learned or instinctive. Investigating behavior requires considerable effort and ingenuity. What seems simple often turns out to be complex, and what appears to be complicated may prove to be relatively simple.

If you wish further information on the psychological bases of *Science—A Process Approach,* the book, *Conditions of Learning,* by Robert M. Gagné, published in 1965 by Holt,

Rinehart, and Winston is highly recommended. Chapter 7 will be of special interest. The Gagné point of view about how young children learn is presented in Appendix A of this *Commentary*, entitled, *The Psychological Issues of Science—A Process Approach.*

DENSITY

Some materials are heavier than other materials. Lead is obviously heavier than Styrofoam, that is, if you have the same volume of each. If you have a large enough amount of Styrofoam, it will be heavier than a small amount of lead.

In science we say that materials are made of matter. In all three states—solid, liquid, and gaseous—matter fills space and it has mass. A measure of how much space a piece of matter occupies is a measure of its volume. You are familiar with several different ways of measuring volume. An equal-arm balance is usually used to measure mass.

OPERATIONAL DEFINITION OF DENSITY

Suppose you have two pieces of matter. These pieces could be almost anything—a glass window pane, a wad of paper, the milk in a drinking cup, the helium in a balloon. How can the mass and volume of these pieces of matter be used to distinguish one piece of matter from the other? The answer to this question is fairly obvious when you know how a scientist answers it, but you might not think of this answer at first. The scientist uses *the mass per unit of volume* of the object. For example, if you were to find the mass of 1 cubic centimeter of window pane and the mass of 1 cubic centimeter* of milk (the same as 1 milliliter), you would have a useful basis for comparing glass and milk; indeed, you could quickly decide whether glass would float on milk.

The mass per unit of volume of substance is called the *density* of the substance. If the densities of two substances are

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*In this background paper, volumes of liquids as well as solids are expressed in cubic centimeters because density is defined as mass per cubic centimeter. In other parts of the *Commentary,* and in all of *Science—A Process Approach,* volumes of liquids are given in milliliters rather than cubic centimeters

to be compared, the units of mass and volume need to be specified. For example, by the above definition, the density of water could be said to be *1, 62.4,* or *1,000* depending on the units of volume used in computing density. Following are several ways to express the density of water.

1. 1 cubic centimeter (1 milliliter) of water weighs 1 gram
2. 1 cubic foot of water weighs 62.4 pounds
3. 1 cubic decimeter (1 liter) of water weighs 1,000 grams

Any of these statements gives the density of water. For this reason, when you or your children talk about densities of substances, you should be sure that the units that have been used are entirely clear to all listeners.

In the metric system, the volume used in expressing density is usually either one cubic centimeter or one cubic meter. The mass is usually measured in grams or kilograms. So, density is expressed as so many *grams per cubic centimeter* or so many *kilograms per cubic meter.* Densities of gases are frequently expressed as *grams per cubic decimeter* or *milligrams per cubic centimeter.*

Finding the density of an irregular chunk of rock may seem difficult at first because you may not remember how to find the volume of an irregular solid. To find its volume, partially fill a graduated cylinder with some water. Then, place the rock in the cylinder and measure the volume of water the rock displaces. Figure 1 reminds you how to do this. In Figure 1, the volume of the material placed in the graduated cylinder is 20 cubic centimeters. Why? (50 cubic centimeters minus 30 cubic centimeters equals 20 cubic centimeters.) Before you determine the rock's density, you will have to determine its mass. Use an equal-arm balance to measure the mass of the rock.

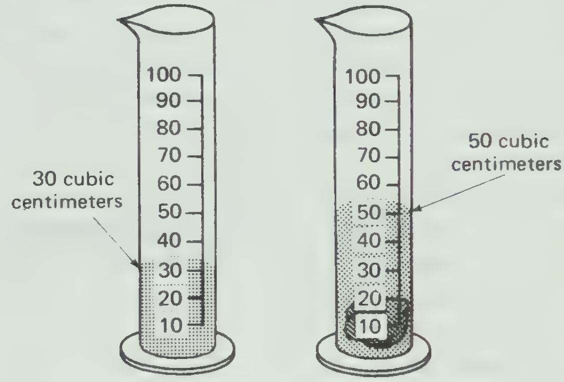

FIGURE 1

A LINEAR RELATIONSHIP BETWEEN VOLUME AND MASS

When you have measured the volume and the mass of the material, you must then compute the density according to the relationship expressed in the definition: $D = \frac{M}{V}$.

Suppose you made some measurements of ordinary glass, lead, and aluminum. You measured the volumes and masses of several pieces of each of these materials, and your record looked like that in Figure 2. These data may be plotted on a graph, as in Figure 3. You will notice that there is a separate line for each material.

Why are the points determined by the number pairs for each material on a straight line? (Is it not reasonable to ex-

Glass		Lead		Aluminum	
Mass, in grams	Volume, in cubic centimeters	Mass, in grams	Volume, in cubic centimeters	Mass, in grams	Volume, in cubic centimeters
21.6	9.0	35.3	3.1	20.0	7.4
5.5	2.3	45.6	4.0	27.0	10.0
13.4	5.6	71.8	6.3	10.0	3.7

FIGURE 2

pect that 3 cubic centimeters of a material will weigh three times as much as 1 cubic centimeter of the same material, and half as much as 6 cubic centimeters?) Why does each line contain the origin? (If you have none of the material, how much will it weigh?) You can compute the density of each of the materials either from the table in Figure 2 or from the graph in Figure 3. If you use the table, you must divide the mass by the volume for any entry. You can readily do this, but if the children in your class are not able to divide decimals, they can use the graph. Look at the line for aluminum. Read from the graph how much 10 cubic centimeters of aluminum weighs. (About 27 grams; hence 1 cubic centimeter weighs 2.7 grams. The density of aluminum is 2.7.)

An interesting relationship between *density* in physics or chemistry and *slope* in mathematics is shown here. By definition, the slope of a line that contains the origin is the ratio, for any point on the line,

$$\frac{\text{y-coordinate}}{\text{x-coordinate}}$$

This ratio is also the density of a material.*

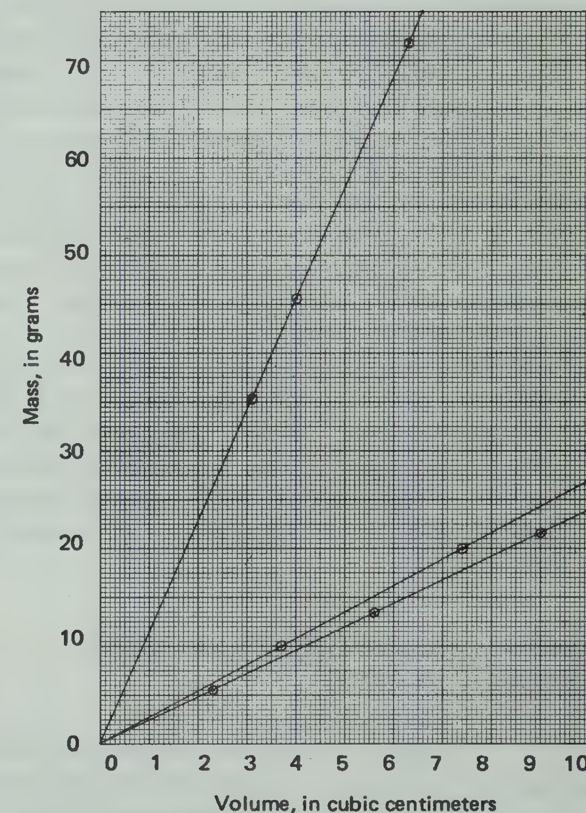

FIGURE 3

THE DENSITY OF WATER AND ICE

What is the density of water? To find the density of water, you need to find the mass of one cubic centimeter of water. But do you need to measure one cubic centimeter exactly? (No, you may use any measured volume, find its mass, and compute the density.)

Pour 15 cubic centimeters of water into one pan of an equal-arm balance. You will find that the 15 cubic centimeters of water is balanced by a mass of 15 grams on the other pan. So, if 15 cubic centimeters has a mass of 15 grams, then one cubic centimeter, of course, has a mass of one gram. The density of water is one gram per cubic centimeter.

What is the density of ice? If a piece of ice has a volume of 55 cubic centimeters, and its mass is 49 grams, then one cubic centimeter of ice has a mass of approximately 0.9 gram. The density of ice is 0.9 gram per cubic centimeter. Ice floats on

*For a discussion of slope, see *Activity 4, Interpreting Data,* in this *Commentary.*

water. Lead and aluminum do not. The density of ice (0.9) is less than the density of water (1.0). The density of lead (11.4) and the density of aluminum (2.7) are more than the density of water. These data suggest that density is related to buoyancy.

DENSITY AND BUOYANCY

What is the density of wood? A chunk of pine wood which has a volume of one cubic decimeter has a mass of about 800 grams. The density of pine wood, therefore, is 800 grams per cubic decimeter. One cubic decimeter is the same as 1,000 cubic centimeters, so we may also express the density of pine wood as 0.8 gram per cubic centimeter. Since pine wood floats on water, you have further support for the hypothesis:

> *If the density of substance A in grams per cubic centimeter is less than 1, substance A will float on water.*

Additional evidence for this hypothesis can be found by determining the densities of other materials and testing them to see if they will float on water. Choose one object that floats and one that does not; then find their densities. Do your data also support the hypothesis? Did you find that in order to measure the volume of the floating object you had to push it down so that it was submerged in the water?

To see why relative densities have an important bearing on buoyancy, you might conduct the following investigation.

1. Find the mass of a small object that floats on water, such as a small block of wood or a piece of paraffin
2. Pour 400 cubic centimeters of water in a 1,000 cubic centimeter graduated cylinder
3. Float the object in the water and record the water level. Suppose the water level rises to 623 cubic centimeters
4. What is the mass of 223 cubic centimeters of water? (223 grams.)
5. Compare the mass of the water displaced by the floating object (223 grams) with the mass of the object

For further evidence, try the same procedure with another irregular object of different material. Do your data support the following statement which scientists call *Archimedes' Principle?*

> *Objects sink in water until the mass of the water displaced is the same as the mass of the object.*

On the basis of this principle, what do you infer will happen

to an object whose mass is greater than the mass of water it will displace? (It will sink when it is placed in water.)

In summary, consider two objects, *C* and *D*. The density of *C* is 1.3 grams/cubic centimeter. The density of *D* is 0.7 gram/cubic centimeter.

What is the mass of 1 cubic centimeter of *C*?
What is the mass of 1 cubic centimeter of water?
Will *C* sink in water? Why?
What is the mass of 1 cubic centimeter of *D*?
What is the mass of 1 cubic centimeter of water?
Will *D* sink in water? Why?

DENSITY OF LIQUIDS

So far, this discussion has been concerned with the density of solids. You may wish to make an investigation of the density of several liquids. What liquids have you seen float on water? Is their density less than the density of water? Does Archimedes' Principle apply to liquids? Does Archimedes' Principle apply to solids in liquids other than water, such as alcohol or mercury? You may wish to raise some of these questions for investigation by your class. Relatively simple investigations that you can conduct at home will provide you with answers that will suggest hypotheses for the children in your class to test.

In order to find the density of a liquid, you must measure the mass and volume of a sample of the liquid and then make a computation or construct a graph to find the density of the liquid. What measuring instruments would you use? (An equal-arm balance and a graduated cylinder.)

The densities of a few liquids in grams per cubic centimeter are given in Figure 4.

Liquid	Density, in grams/cubic centimeter
Gasoline	0.68
Ether	0.71
Turpentine	0.87
Cottonseed oil	0.92
Sea water	1.02
Glycerine	1.26
Carbon tetrachloride	1.60

FIGURE 4

DENSITY OF GASES

The density of air near the surface of the earth is quite varied. It depends upon the humidity, the temperature, and other factors. However, the average density of air is about 1.2 grams per cubic decimeter, at atmospheric pressure and room temperature. A density of 1.2 grams per cubic decimeter is the same as 1.2 grams per 1,000 cubic centimeters, or 0.0012 gram per cubic centimeter. In scientific notation, this may be written as 1.2×10^{-3}.

Helium is used to fill children's balloons at fairs and carnivals. When released, these balloons rise, as many tearful children know. You might say that these balloons tend to float on top of the air just as wood, released under water, will rise to the top of the water and float there. Do you think that the density of the helium in a child's balloon is less than,

greater than, or the same as, the density of air? (The density is less than 1.2 grams per cubic decimeter, since the helium-filled balloon tends to rise. Measurements indicate that at ordinary temperatures and pressures the density of helium is about 0.18 gram per cubic decimeter. At higher altitudes, air is thinner and the density is less than at lower altitudes. Therefore, the helium-filled balloon will rise to the altitude at which air has a density the same as helium. However, we are not accounting for the small effect due to the mass of rubber in the balloon itself and the string which closes the neck of the balloon.)

Does air at a higher or lower temperature have a greater density? Since heated air tends to rise to the top of a room, you probably would say that air at a higher temperature has a lower density.

What do you have to do to find the density of a gas? (Measure the mass and volume of the gas, and compute the density.) Think about how you could measure the volume and mass of a gas. This may present a problem. Gases can be compressed more easily than liquids or solids. What pressure will you use?

In *Science—A Process Approach,* the children are not asked to find the density of gas. If some children are interested in finding the density of a gas, refer to the book, *Introductory Physical Science*, produced by the Introductory Physical Science Group of the Education Development Center and published in 1967 by Prentice-Hall, Inc. The experiment on the density of carbon dioxide described on pages 29–31 is within the ability level of pupils studying Parts F and G.

SOLUTIONS

If you add a pinch of sodium bicarbonate (baking soda) to a glass of water and stir the mixture for a minute or so, the sodium bicarbonate disappears and the water looks exactly as it did before the sodium bicarbonate was added. We say that the sodium bicarbonate *dissolved* in the water to form a *solution.*

If you add more sodium bicarbonate to the solution, it will dissolve up to a point. At room temperature, for example, if you add 11 grams of sodium bicarbonate to 100 milliliters of water, only 10 grams will dissolve. The remaining 1 gram will remain as a solid in the bottom of the container. The solution is now called a *saturated solution.* The *solubility* of sodium bicarbonate at room temperature is about 10 grams per 100 milliliters of water.

For most substances that are *soluble* in water, the solubility increases with temperature. The solubility of sodium bicarbonate at various temperatures is shown in Figure 1. If you prepare a saturated solution of sodium bicarbonate at 52°C (15 grams/100 milliliters of water), and cool the solution to 22°C, solid sodium bicarbonate will form gradually until there are 5 grams of solid sodium bicarbonate at the bottom of the container. During the time that the solid sodium bicarbonate is coming out of (precipitating from) the solution at 22°C, the solution is *supersaturated.*

Some substances form supersaturated solutions from which the solid *precipitates* very slowly (hours or even days). Alum is an example of such a substance. This property of alum makes it possible to grow large crystals of the substance. If a small crystal of alum is placed in a supersaturated solution of the material, and the solution is left undisturbed for several days, the small crystal will slowly grow into a larger one.

The solubilities of many substances increase a great deal as the temperature of the water is increased. Two examples of

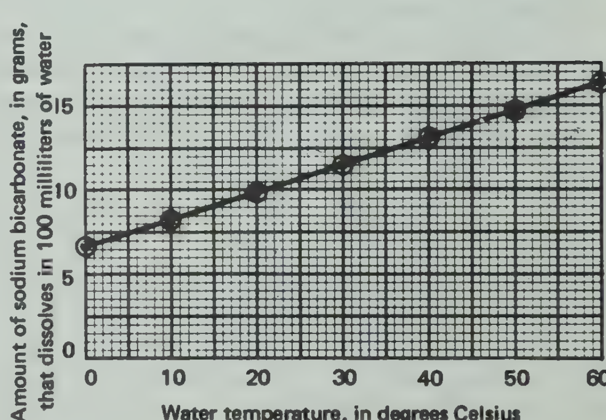

FIGURE 1

such substances, alum and copper sulfate, are shown in Figure 2. The solubilities of some substances, sodium chloride for example, increase only slightly as temperature is increased. A few substances, such as sodium carbonate (washing soda), actually decrease in solubility as temperature increases. (See Figure 2.)

Most solids that are soluble in water are insoluble, or only slightly soluble, in liquids like alcohol. Figure 3 shows the relative solubilities of a few substances in water and in ethyl alcohol. All of these substances have intermediate solubilities in mixtures of water and alcohol—the more alcohol the lower the solubility. This fact provides a way of precipitating solids from solution. If alcohol is added to a solution containing 20 grams of copper sulfate per 100 milliliters of water, some of the copper sulfate will precipitate. The amount that precipitates depends on the amount of alcohol added.

Solutions of many substances are frequently preferred to the pure materials because of convenience. Medicines (particularly children's medicines) are often given in solution because they are easier to swallow. In many cases, the actual amount of the drug to be given is very small, and a solution provides a convenient way to measure out a very small dose. Several chemicals found in the home are in solution because the pure chemical is dangerous. Liquid bleach is a very dilute solution, as is common vinegar. Many food flavorings are packaged as solutions either because the pure flavoring is so potent that a tiny pinch would be too much, or because the pure flavoring doesn't dissolve readily in water.

We are usually interested in the amount of material dissolved in water or alcohol to make a solution. We need some way of knowing how much of the solid we are getting when we pour out 10 milliliters or 100 milliliters of solution. One method is to state that the solubility of sodium bicarbonate is 10 grams per 100 milliliters of water. We say, "At room temperature, the *concentration* of a saturated solution of sodium bicarbonate is 10 grams/100 milliliters or 0.1 gram/milliliter." By expressing the concentration in grams/milliliter of solution, we can easily determine the amount of sodium bicarbonate that we would have in any amount of solution. If we poured out 5 milliliters of the solution, we would have 0.5 gram of sodium bicarbonate

$$\left(5 \text{ ml of solution} \times \frac{0.1 \text{ g of sodium bicarbonate}}{1 \text{ ml of solution}}\right).$$

Ten milliliters of solution would contain 1.0 gram of sodium bicarbonate.

Sometimes, concentration is given as a percent of the *weight* of the solution. For example, a bottle of vinegar is normally labeled "5% acetic acid." If you weigh 100 grams of vinegar,

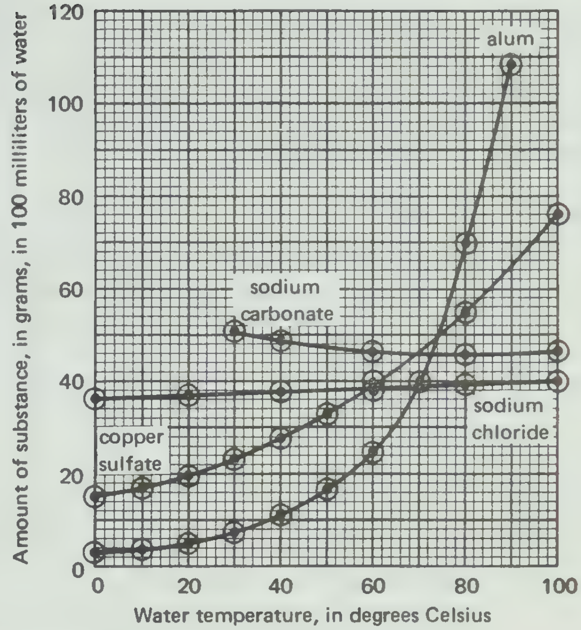

FIGURE 2

Substance	Solubility at room temperature in grams/100 milliliters	
	In water	In ethyl alcohol
Potassium iodide	140	5
Ammonium chloride (sal ammoniac)	39	1
Sucrose (cane or beet sugar)	200	0.6
Copper sulfate	21	0.2
Sodium chloride	36	0
Alum	6	0

FIGURE 3

you have 5 grams of acetic acid and 95 grams of water (100 g x .05 = 5 g.)

Since it is more convenient to measure the volume than the mass of a liquid, we normally express concentration in grams/milliliter in these exercises.

EVALUATION

1. If you made a solution of citric acid by dissolving 450 grams of citric acid in enough water to make 1,000 milliliters of solution, what would the concentration be in grams per milliliter of solution?
2. If you wanted to use 9 grams of citric acid, how much of this solution would you measure?

COMMENTS ON EVALUATION

1. If there are 450 grams of citric acid in 1,000 milliliters of solution, then the concentration is

$$\frac{450\text{ g}}{1{,}000\text{ ml}} = 0.45\text{ g/ml.}$$

2. $$\frac{0.45\text{ g}}{1\text{ ml of solution}} = \frac{9\text{ g}}{\text{volume of solution}}$$

$$\begin{array}{l}\text{volume of solution} \\ \text{containing 9 g}\end{array} = \frac{9}{0.45} = 20\text{ ml.}$$

CHEMICAL INDICATORS

Have you ever noticed what happens when you squeeze some lemon juice into a cup of tea? If not, try it. Pour equal amounts of tea into three small juice glasses. Add some lemon juice to one of the glasses. (If you do not have lemon juice, use vinegar.) What happened? Did the color become paler? Perhaps the color changed because it was diluted by the liquid you added. Add the same amount of water to one of the other glasses. Is there still a difference in color? There should be. Now, add a little ammonia to the third glass. You probably noticed that the color turned darker.

A color change, such as the one just described, is evidence of a chemical change in a system.* A chemical reaction has taken place. Not all chemical changes produce color changes, but in this paper we are going to limit our discussion to chemical changes where color *does* change. In fact, we will limit our discussion to those substances that change color when acids (like lemon juice or vinegar) or bases (like ammonia or washing soda) are added to them. Such substances are called *acid-base indicators.*

Tea is not a very good acid-base indicator because the change in color is not very great. In fact, the change is more in shade (lighter or darker) than in color. A better acid-base indicator is one which has a different color in an acid than in a base. There are many substances that react this way. Some of them are natural products; others are synthetic.

Red colored vegetables and flowers contain acid-base indicators that are red in acids and blue or green in bases. If you

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*It is possible, of course, to produce a color change without a chemical reaction. For example, if water colored with blue food coloring is mixed with water colored with yellow food coloring, the mixture will be green, even though no chemical change occurs.

would like to test some of these natural acid-base indicators, you can add vinegar or ammonia to the following solutions.

Water in which red cabbage has been boiled
Beet juice
Grape juice (red) or red wine
Blackberry jelly (diluted with water)

Another natural indicator that is prepared by fermenting an extract of a certain kind of lichen is called *litmus.* Litmus paper is sold by laboratory supply houses and some drug stores. Litmus paper is white absorbent paper that has been soaked in a solution of litmus and allowed to dry. If litmus paper is dipped into an acid, it turns red. (Most litmus paper is pink, rather than red, in acid solutions.) In a base, litmus paper turns blue. If you have some litmus paper, dip a piece of it into some white vinegar. Add clear household ammonia to the vinegar drop by drop and observe the change in color of the litmus paper. Compare the color with the color of a strip of litmus paper which you have dipped in ammonia. Did you observe that as the red color began to change, the change was a gradual one from red to purple and finally to blue? The intermediate purple color indicated that the solution was neutral. That is, there were equal amounts of acid and base in the solution.

Congo red is a synthetic acid-base indicator that is used in *Observing Color Changes, Observing 5, Exercise j,* Part A. Congo red is blue in acids and red in bases—just the opposite of litmus. If you have some Congo red paper and some litmus paper, you might like to make the following investigation. Put a piece of each kind of paper into a few milliliters of white vinegar. The Congo red paper should turn blue and the litmus paper red. Now, add clear household ammonia with a medicine dropper and observe the changes in color. You will note that the Congo red paper turns purple and then red while the litmus paper is still red. You will probably have to add at least twice as much ammonia to make the litmus paper turn blue. A solution that is neutral (purple color) to Congo red indicator is acid to litmus.

Indicators such as litmus and Congo red can be used to find out how acidic or how basic a solution is. Scientists use a scale called a *pH scale** to measure the acidity or basicity of a solution. The scale ranges from 1 to 14. A pH of 1 indicates a strongly acidic solution and a pH of 14 indicates a strongly basic solution. Pure water is neutral and has a pH of 7. Any solution with a pH less than 7 is acidic and any solution with

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*If you are interested in learning more about the pH scale, consult a general chemistry text.

a pH greater than 7 is basic. The degree of acidity increases from 7 to 1 and of basicity from 7 to 14.

Different indicators change color at different pH's. Congo red is blue below pH 3 and red above it. Litmus is red below pH 7 and blue above it. Now do you see why Congo red paper turned color before litmus paper as you added ammonia to the vinegar? Before you started to add ammonia, the vinegar had a pH less than 3, so the Congo red paper was blue and the litmus paper was red. As you added ammonia, the acidity of the solution decreased and the pH increased. At pH 3, the Congo red paper turned red, and the litmus paper remained red. It was not until you added enough ammonia, to raise the pH of the mixture to 7 that the litmus paper, started to turn blue.

MAGNETISM*

For thousands of years, man has known about a property of matter called *magnetism.* Soon after methods of producing metallic iron were invented several thousand years ago, the ability of lodestone (the mineral now called magnetite) to attract iron was discovered. If an iron bar is stroked several times with a piece of lodestone, the bar becomes a magnet and can attract other pieces of iron.

A magnet has two poles called *N* and *S*. When a magnet is suspended so that it can swing freely in a horizontal position, it turns until the *N*-pole (pronounced *en-pole*) is pointing north, and the *S*-pole(pronounced *ess-pole*), south. A curious fact about a magnet is that if it is broken into pieces, no matter how small, each piece is a magnet with *N* and *S* poles. If you have a ceramic magnet to spare, you might confirm this. You can easily break one with a hammer. If you push these pieces of the magnet together, you will find that in certain orientations the ends of the pieces stick together quite firmly. In other positions, you have to push to keep the ends of the magnet together; if you let go of them, they will fly apart. The explanation of this is that unlike poles (*N* and *S*) attract each other and like poles (*N* and *N* or *S* and *S*) repel each other.

There is a magnetic field surrounding any magnet. You cannot see the field, of course, but you can demonstrate that it is there. Place an index card over a bar magnet and sprinkle a few iron filings evenly over the surface of the card. Tap the card lightly a few times. What do you observe? Did you get a pattern similar to Figure 1?

*You may enjoy making some of the observations suggested in this paper. You can do several of them with a bar magnet and a magnetic compass. For the rest, you will need the following: a ceramic bar magnet, iron filings, a 1.5-volt dry cell and holder, 1 meter of fine (24 gauge is satisfactory) insulted copper wire, a stove bolt or large nail.

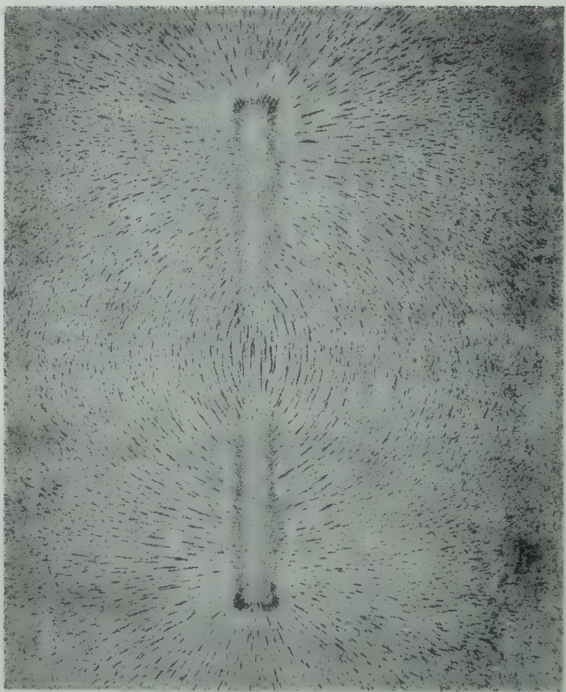


FIGURE 1

In the magnetic field of the bar magnet, each iron filing becomes a little magnet with an *N* and an *S* pole. These little magnets line up, *N* to *S*, in chains that spread out from each pole. Some of the chains form curves from one pole to the other. The lines thus formed are sometimes called *lines of force.* It is best not to think of them as lines of force, but rather to think of them as showing the *direction of the magnetic field.*

A magnetic compass points in the direction of the magnetic field when it is placed close to a magnet. Place your compass close to a magnet and note the direction in which the needle is pointing. Move the compass to several other positions around the magnet. Do the compass needle directions correspond, in a general way, with the directions in which iron filings line up (Figure 1)?

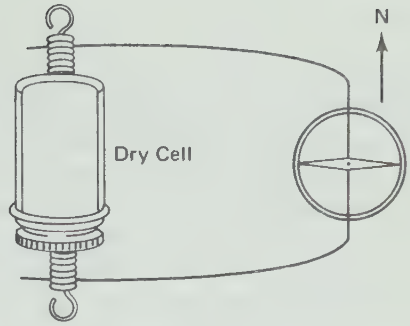


FIGURE 2

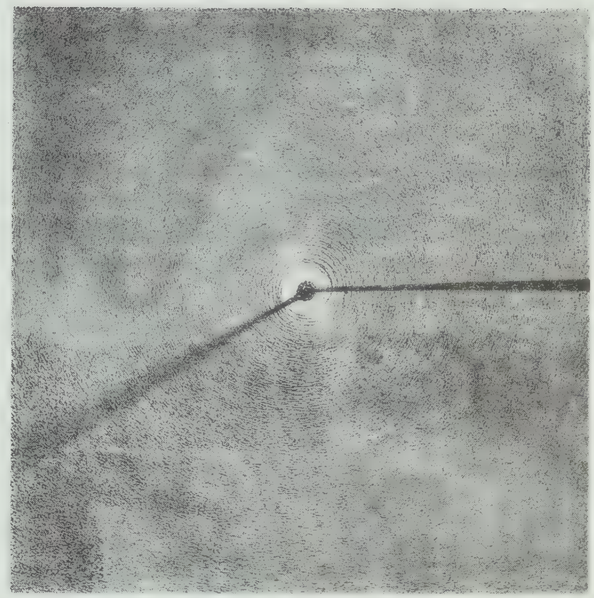


FIGURE 3

ELECTROMAGNETS

Connect the two poles of a 1.5 volt-dry cell with a piece of wire and place a magnetic compass under the wire (Figure 2). Orient the wire above the compass in a north-south direction. The compass needle will line up in an east-west direction. Disconnect the wire from one end of the dry cell. The compass needle should swing to a north-south direction. What is the direction of the magnetic field around a wire through which an electric current flows? The compass indicates that it is perpendicular to the direction of the wire. Actually, the direction of the field is circular around the wire. (Figure 3.)

Wrap fine insulated wire around a nail or bolt, as in Figure 4. Connect the ends of the wire to a dry cell. Bring one end of the bolt close to a paper clip. The paper clip should be attracted to the bolt, if you have sufficient turns of wire around the bolt and if your dry cell is not worn out. Disconnect the wire from one end of the dry cell. Does the bolt still attract the paper clip? It may attract the clip for a few seconds but should soon become a non-magnet again. The arrangement you have constructed is called an *electromagnet.* If you like, you can use your magnetic compass or a card and iron filings to demonstrate the direction of the field around your electromagnet.

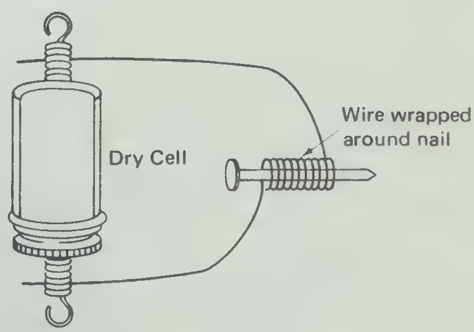


FIGURE 4

Electromagnets are widely used in industry. You may have seen pictures of electromagnetic cranes that are used for moving heavy loads of scrap iron or other iron objects. There is at least one electromagnet in many homes. A door chime rings when the button is pressed. Current flows through a coil of wire and converts the coil and its iron core into an electromagnet. The iron core of the electromagnet is free to move, and it moves in the magnetic field inside the coil until it strikes a metal bar that chimes when it is struck.

THE EARTH IS A MAGNET

Your magnetic compass points in a north-south direction because the earth is a magnet (Figure 5). However, the poles of the earth-magnet do not coincide with the geographic poles. As a result, a magnetic compass does not point to geographic north in most places on the earth, but points either east or west of north. Figure 6 shows how far east or west of north a compass points in different parts of the United States. Notice that along a line extending from eastern Georgia to northern Michigan the compass needle *does* point to geographic north. In all of the United States east of that line, the needle points west of true north, and west of the line it points east of north. The number of degrees east or west (called east or west *declination*) is indicated on the map. The declination for any location changes a little bit every year, and over a period of a century or so it may change by many degrees.

Why the earth is a magnet is not known with certainty. It seems probable that the liquid nickel-iron core of the earth is moving with respect to the mantle. In moving, it produces electric currents which have magnetic fields associated with them. According to this explanation, the earth is a huge electromagnet.

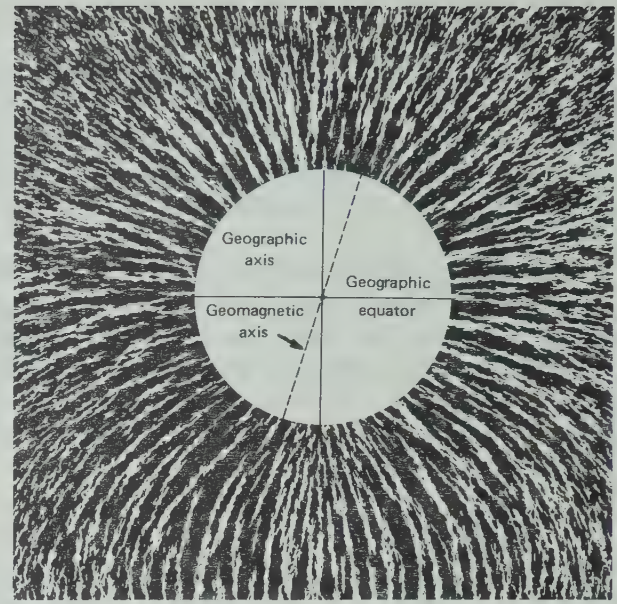


FIGURE 5

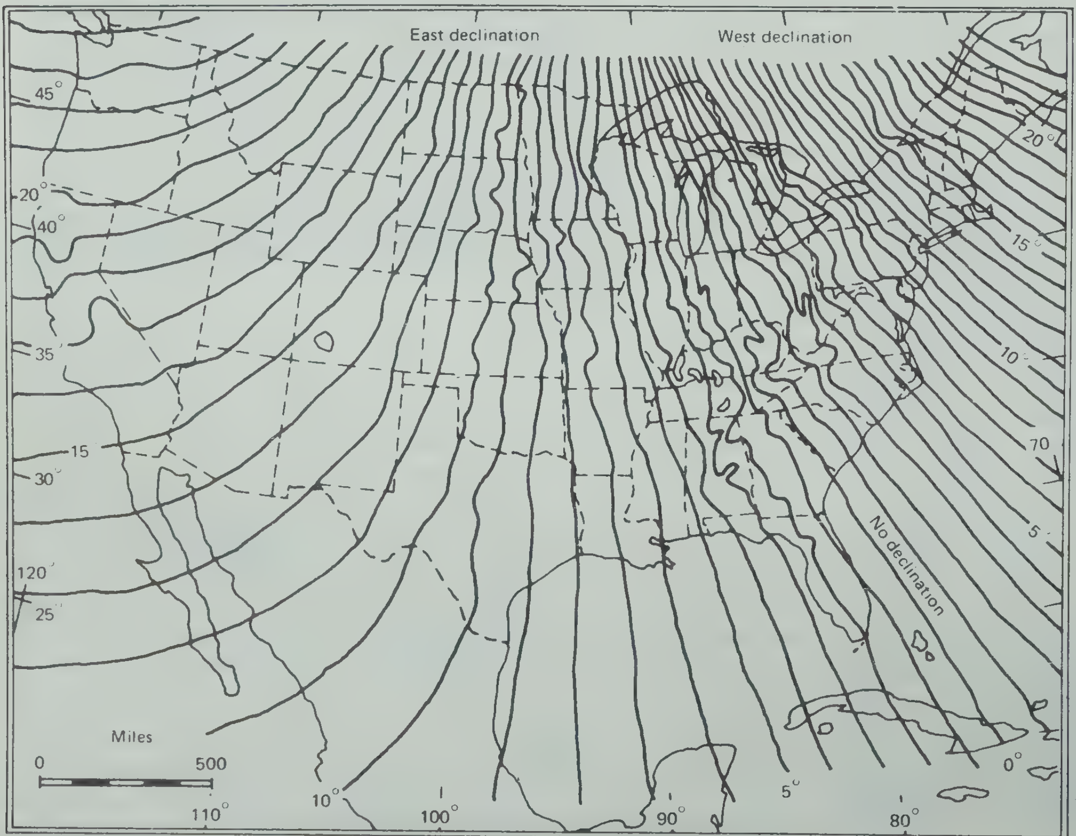


FIGURE 6

FERMENTATION

Green plants use energy from sunlight and produce organic compounds and oxygen. Animals obtain energy to sustain life by combining organic compounds with oxygen to produce carbon dioxide and water. Some organisms can obtain energy from organic compounds without combining them with oxygen. The process by which they do this is called *fermentation.* The most familiar organisms that carry out this process are the yeasts that are used to make bread, beer, and wine. These yeasts can convert sugar into carbon dioxide and alcohol (ethanol).

Fermentation is a step-by-step process. Yeast breaks down sugar through a series of reactions until the final products are carbon dioxide and ethanol. Carbon dioxide forms bubbles in the fermentation mixture, and it is these bubbles that make bread dough rise and produce the head on a glass of beer and the bubbles in sparkling wines and champagnes. The ethanol produced by fermentation gives beer and wine their intoxicating properties. Most of the ethanol that is produced in bread dough is driven off when the bread is baked.

The rate at which yeast ferments sugar can be determined by measuring the amount of carbon dioxide that is being produced. This can be done in various ways. One procedure is to measure the rate at which bubbles of carbon dioxide come out of a fermentation mixture when it is in an apparatus like that shown in Figure 1. The rate of fermentation might be expressed as the number of bubbles of carbon dioxide produced per minute.

The rate of fermentation of sugar by yeast is affected by a number of variables, such as the amount of sugar, the amount of yeast, and the temperature of the fermentation mixture.

For example, if the amount of yeast in a fermentation mixture is kept constant, increasing the amount of sugar in the mixture increases the fermentation rate. However, there is a sugar concentration (different for various yeasts) beyond which the addition of more sugar does not increase the fermentation rate. Similarly, increasing the temperature increases the fermentation rate only up to a point. This point is different for different yeasts. At temperatures above the critical point, yeast cells are killed and the rate of fermentation decreases. The amount of ethanol in the fermentation mixture also affects the fermentation rate. As alcohol concentration increases, the rate of fermentation decreases and finally stops. Brewing and baking yeasts can ferment sugar until the alcohol concentration is about 12 percent.

Ethanol is not the only alcohol that is produced in the fermentation process. A small amount of the sugar that is fermented by brewer's yeast is converted to fusel oil, which is a mixture of five or more different alcohols. Under normal conditions, yeast ferments about two percent of the sugar to an alcohol called glycerol (glycerine). However, by adding various substances (sodium hydroxide or sodium bisulfite) to the fermentation mixture, it is possible to force the yeast to ferment 25 percent or more of the sugar to glycerol. This process has been used for the industrial production of glycerol.

Another familiar substance produced by fermentation is lactic acid, the acid in sour milk. Lactic acid is produced from milk sugar (lactose) by bacteria called *Lactobacilli.* In this fermentation, no carbon dioxide is produced, so souring milk does not foam as beer does.

For many years, scientists have speculated on the possibility that living organisms might occur on the moon and on planets such as Mars and Venus. The moon has no atmosphere, Mars a very sparse one, and Venus an atmosphere containing little or no oxygen. If living organisms exist on any of these three bodies, they might be expected to metabolize by some sort of fermentation process, since no oxygen is available for respiration.

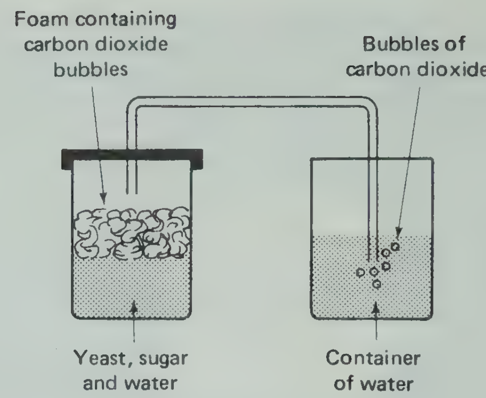


FIGURE 1

PHOTOSYNTHESIS

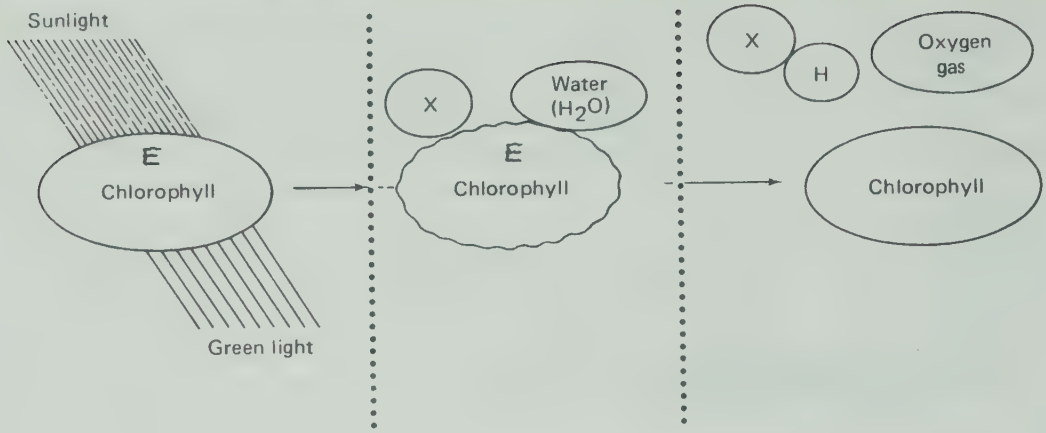
All of the energy that sustains life on the earth comes from the sun as radiant energy. Green plants use the energy of sunlight to synthesize organic compounds such as starch and cellulose. The process is called *photosynthesis.* Herbivorous animals eat plants and use the organic compounds contained in them to grow, to sustain life, and to reproduce. Carnivorous animals in turn use the tissues of herbivorous animals for their life processes. Many lower forms of animal life use the waste products of higher animals. Hence, without photosynthesis, the earth would be a lifeless planet.

The master molecule in photosynthesis is the green substance, *chlorophyll.* Chlorophyll is found in the plant cell in round bodies called *chloroplasts,* which are easily seen through a microscope. Chlorophyll has a green color because it absorbs red and blue light and transmits or reflects green light. It is primarily the energy of the red light that is used in photosynthesis. In addition to chlorophyll, a plant needs light, water, and carbon dioxide to carry on photosynthesis. Overall, the process can be shown this way:

Water + Carbon Dioxide + Light → Organic Compunds + Oxygen

The process involves many steps (chemical reactions represented by the arrow), most of which have been discovered in relatively recent extensive research.

The initial steps in photosynthesis are diagrammed in Figure 1. The radiant energy, , of the red light that is absorbed by chlorophyll is used to decompose water in the plant cell. The oxygen in water (H_2O) is converted to oxygen gas which escapes from the plant into the air through small open-



X represents the hydrogen holding substances

FIGURE 1

ings in the leaves called *stomates.* The hydrogen of the water is held by certain substances in the cell, to be used later in the synthesis of organic compounds. These steps are illustrated in Figure 1. The substances that hold the hydrogen (H) from the decomposed water are represented by the symbol X , and the resulting product is represented by XH . After the chlorophyll has used the energy it absorbed to produce XH and oxygen gas, it is again ready to absorb more energy from sunlight and repeat the process.

Carbon dioxide gas from the air enters the leaf through the stomates and is used by the leaf for a complex series of reactions that produce many organic compounds (such as starch, cellulose, and proteins). Organic compounds are made basically of carbon and hydrogen, but also include other elements, such as oxygen, nitrogen, sulfur, and phosphorus. All of the carbon in the organic compounds in plants comes from carbon dioxide. The hydrogen comes from water. A simplified representation of the process which produces the organic compounds is shown in Figure 2 where XH is the hydrogen-carrying substance produced in the reactions shown in Figure 1.

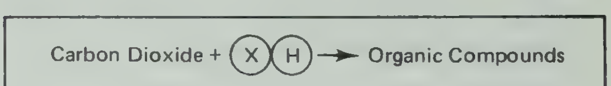


FIGURE 2

In a very general way, animals reverse the process of photosynthesis. Many of the metabolic steps (chemical reactions) in animals are different from those in plants, although some are remarkably similar. Animals use the elements and the energy of organic compounds produced by plants, and they use oxygen from the air; the major end products of their metabolic processes are carbon dioxide and water. This process is called *respiration.* One major difference between these processes is that plants take in radiant energy (light) while animals give off thermal energy (heat).

Can plants respire as animals do? Yes, respiration goes on in plant cells just as it does in animal cells. But in sunlight, photosynthesis is a much greater source of energy for green plants than is respiration. However, even in sunlight, some parts of plants—such as sprouting seeds, seedlings, and tips of rapidly-growing shoots—respire like animals. These plant parts use oxygen from the air and release carbon dioxide, just as all plants do in the absence of light. This fact may have given rise to the old tale that it is unhealthy to sleep in a room where there are plants. There is no basis for the belief, since the amount of carbon dioxide released in the dark by a house plant is small.

It is the hope of some scientists that an understanding of the process of photosynthesis will be followed by the development of ways to control it, or at least to simulate it. Imagine what effect it would have on the world's food supply if a way were found to use the energy from sunlight to synthesize food without having to grow plants. So far, no way has been found to do this.

APPENDIX A: CHRONOLOGY OF DEVELOPMENT

A brief chronology of the development of *Science—A Process Approach* is provided in this Appendix, for the historical record, and to make more clear how the writing and tryout were related, and how and at what stages the 500 scientists and teachers contributed to the developmental process.

1961

A feasibility study sponsored by the American Association for the Advancement of Science with support of the National Science Foundation brought scientists, educational administrators, and teachers together to consider the preparation of science materials for elementary and junior high schools by teams of teachers and scientists. Conferences were held in St. Louis, Berkeley, and Washington. Participants in the conferences urged that a national commission be appointed to work with several centers in planning and developing instructional materials for pre-high school science and to give direction to a large-scale coordinated attack on problems of science education. A report of the feasibility study was published in *Science,* June 23, 1961, Vol. 133, No. 3469, pages 2019–2024.

Spring and Summer 1962

The American Association for the Advancement of Science appointed a Commission on Science Education, which as a first activity sponsored two eight-day conferences, one at Cornell University in June and the other at the University of Wisconsin in August. Scientists, teachers, and school administrators came together at these conferences to consider the impact of the new high school science courses, to review research in science education and in learning, and to seek ways of improving science education in elementary and junior high schools. The conferences recommended that the Commission sponsor the development of instructional materials beginning at the kindergarten level, and that these materials stress the processes of science.

1962–63

A panel prepared a statement of purposes and objectives of science education in school, and a review of research in science education was published. The Commission staff formulated plans for the development of a science program for the primary grades, and with the help of scientists, science educators, and teachers prepared preliminary outlines of course materials.

Summer 1963

At Stanford University in an eight-week summer writing session, thirty-five scientists and elementary school teachers wrote 100 exercises for use in primary grades. Competency measures were prepared to be used by tryout teachers in reporting pupil achievement. A *Teachers Guide* was also prepared. After staff editing, these materials were published as *Science—A Process Approach,* Parts One through Five, Experimental Edition, prepared for testing in elementary schools. The writers worked in close proximity to the School Mathematics Study Group which advised them on the preparation of mathematics exercises needed in the science program. Whenever possible, the writers tried out drafts of exercises in demonstration classes.

1963-64

The experimental edition prepared in the summer of 1963 was tried in twelve centers by 106 tryout teachers and approximately 3,000 children. A science consultant and a coordinator assigned to each tryout center helped orient the teachers and assisted in other ways. The teachers submitted a feedback form and scores on competency measures after each exercise taught.

Summer 1964

Again at Stanford University, fifty scientists and teachers, working for eight weeks, revised the materials prepared in the summer of 1963 and wrote additional exercises and competency measures. The *Teachers Guide* was extended for publication as a *Commentary for Teachers.* After staff editing, the revised and new exercises were published as *Science—A Process Approach,* Parts One through Six, Second Experimental Edition.

1964-65

Parts One through Six of *Science—A Process Approach* were tried out by eighteen teachers in kindergarten through grade 5 in each of fourteen centers. Approximately 7,000 children studied the program—some new to the program and others in the second year. Again, center consultants and coordinators directed work in the tryout centers, and tryout teachers submitted feedback forms and scores on competency measures for each exercise.

Summer 1965

Fifty scientists and teachers worked at Michigan State University for eight weeks on the revision of the Second Experimental Edition of *Science—A Process Approach.* Thirty new exercises for Parts Six and Seven were written and all of the earlier materials were revised. After staff editing, the materials were published as the Third Experimental Edition of *Science—A Process Approach*, Parts One through Seven. Booklets containing competency measures for each exercise in the seven Parts and the first edition of the *Science Process Instrument,* a device for testing the progress of an individual child through the process hierarchies, were printed. The *Commentary for Teachers* was revised and extended.

During one week of the summer writing session, two key representatives from each tryout center came to a teacher education conference to try out and evaluate an inservice program for teachers. The objective was to enlist assistance from the field in identifying and dealing effectively with problems teachers face in teaching science to children by the process approach.

1965-66

Each of the fourteen tryout centers assigned additional teachers in the intermediate grades (4, 5, and 6) to *Science—A Process Approach,* and fewer primary teachers took part. Some of

the children were in the program for the third, some for the second, and others for the first year. The tryout teachers continued to submit competency measure reports and their evaluations of the exercises on revised feedback forms. The *Science Process Instrument* was tried in several of the centers, both with children in *Science—A Process Approach* classes and in classes with another science program. Center consultants and teachers also reported on their experiences in the inservice education program. A two-day conference of center consultants and tryout teachers was held in Washington, D.C., in January.

Summer 1966

At the University of Maryland, thirty-five teachers and scientists revised Parts Five, Six, and Seven of the Third Experimental Edition of *Science—A Process Approach,* the competency measures, the *Commentary for Teachers* and the inservice program, and the *Science Process Instrument.* Additional competency measures were written as group tests for use in intermediate grades. A second conference for teachers from the tryout centers and for representatives of school systems using *Science—A Process Approach* at their own expense (not official tryout centers) convened for eight days during the writing session. Again, the teacher education materials were tried out, and the effects of the program on teachers were measured.

Most of the writers worked for five weeks, with about one-third of them remaining for two additional weeks. After staff editing, the materials produced in the summer were published as Parts Five, Six, and Seven, the First Revision of the Third Experimental Edition. Revised editions of the competency measures and *Commentary for Teachers* were published.

1966—1967

Eighty-five percent of the 112 tryout teachers in fourteen centers were teaching in the intermediate grades. Most of the centers also included one third-grade teacher. Tryout teachers continued to meet in inservice sessions with a science consultant. At a two-day conference in Washington in the spring, they reported on and compared teaching experiences. They also reported competency measure scores and feedback comments on each exercise taught. During this year, films were made of classes in the University of Chicago Laboratory Schools and in Monmouth, Illinois.

Xerox Corporation was selected to further develop the materials of *Science—A Process Approach* and to produce and market the entire program in the United States and its territories. Xerox published Parts A, B, and C (formerly called Parts One, Two, and Three) in late spring together with a *Hierarchy Chart* covering the behavioral hierarchies for the basic processes. Xerox also made available kits of materials for all Parts of the program.

Summer 1967

Twenty-four scientists and teachers met in a six-week writing session at the University of Maryland to revise Parts Six and Seven of *Science—A Process Approach*, and various evaluation instruments. Copy was prepared for the Second Edition of the *Guide for Inservice Instruction* with booklets of *Response Sheets* and two forms of the *Process Measure for Teachers* to be used in inservice classes. Conferences were held at several universities to assist teachers who were planning to teach the program, to inform school administrators about the program, and to train teachers of inservice programs.

1967-68

Parts Six and Seven, Fourth Experimental Edition, were published in the fall. Tryout of these two revised Parts was continued in eleven centers by 48 tryout teachers. A number of fourth-grade teachers tried out a final revision of Part Five as prepared for the AAAS-Xerox edition. The Commission staff prepared copy for the monograph, *An Evaluation Model and Its Application*, Second Report, published in April; revised the *Commentary for Teachers*; and prepared the final revision of the *Hierarchy Chart* for the basic processes. Part D (formerly Part Four) was published by Xerox in late spring.

Summer 1968

Several scientists and teachers joined with the staff to revise Parts Six and Seven following the tryout of the Fourth Experimental Edition. Others served as consultants to and members of a joint AAAS-Xerox committee in preparing copy for the Xerox publication of the first part of the *Guide for Inservice Instruction* and prepare copy for an extension of the *Guide* to include Parts Five through Seven.

Summer 1968-69

Xerox published Part E (formerly Part Five) in the fall. The staff conducted further validation studies of the *Science Process Instrument.* New elements of revised Parts Six and Seven were tried and reported on by experienced tryout teachers. After a final review of tryout suggestions, these Parts were submitted to Xerox. The Commission staff prepared final copy for the *Commentary for Teachers*.

APPENDIX B: PSYCHOLOGICAL ISSUES IN *SCIENCE—A PROCESS APPROACH*

I think that all of you who are working with the exercises of *Science—A Process Approach* realize that you are engaged in a great experiment. Furthermore, it is an experiment which itself attempts to follow and to use the methods of science. Particularly, this experiment is one which is quite explicit about its goals. The hypotheses that are being tested are based upon a straightforward logic, and they are open *to examination by any intelligent person, whether scientist, teacher, parent, or even student. As with all scientific hypotheses, they may be incomplete, or they may even turn out to be entirely incorrect—nevertheless, it would be a rare person indeed who would not agree that they are well worthy of the effort of testing. What we are all engaged in is the enterprise of finding out just how well these hypotheses work out.

What are these hypotheses, and what is their derivation? This is what I should like to describe to you, as well as I can. They have not been adventitiously derived. Instead, they represent a serious and systematic view of how scientific capabilities may be developed within the human individual, of how he can become an adult who is attuned to the complexities of knowledge which represent our "scientific" way of understanding the modern world.

Objectives

We begin with an idea of what we want to accomplish—what is it we want the individual to be able to do—how is it we want him to function in today's world. Most scholars and commissions of scholars who have studied the question of educational goals have emphasized three purposes:

1. vocational—the individual should be able to pursue a satisfying life work;
2. citizenship—the individual should be able to exercise responsible citizenship in his relations with other people in his community, state, and nation; and
3. self-fulfillment—the individual should be able to obtain and share with others aesthetic satisfaction.

Science education has all of these goals, and none should be neglected. Of course, we are interested in establishing the conditions of education which will make it possible, for those who

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*A lecture delivered to regional conferences of tryout teachers, 1965, by Robert M. Gagné, modified to make reference to current materials, as appropriate. The lecture was published in the monograph, *The Psychological Bases of Science—A Process Approach,* AAAS Miscellaneous Publication, 65-8.

are capable, to become creative and productive scientists—the vocational goal.

Science education is also legitimately concerned with responsible citizenship—we are interested in developing a citizen who understands the ways of science and scientists, the costs of science, the societal benefits of science, the determination of public policy about science. In other words, we want him to possess what some have called scientific literacy—to be able to read about science in newspapers or elsewhere, and to make responsible judgments about what he reads or hears.

And by no means least, we should like our student to appreciate science, to experience personally the satisfaction of scientific discovery, the compelling experience of inference from systematically organized facts, the intellectual finality of deduction from a general principle to a specific instance. We want him to know from these experiences that "beauty" in science is not just a metaphor, but an attainable intellectual experience.

Alternative Approaches

There surely must be a great deal of agreement on these goals of scientific education. But when one gets to the practical matter of how to achieve them, there are disagreements. When you bring together a group of physicists, biologists, chemists, earth scientists, and mathematicians to try to agree on what science education should be, the disagreements can get pretty lively. And when you add to this the startling idea that one might try to begin designing such education with the earliest grades of school—one reaches a condition which approaches pandemonium at times. There is of course something to be said for beginning at the highest level and working downwards. There are also advantages to working the other way. At any rate, as you know, the latter is what we tried to do, and we *did* have the periods of pandemonium.

In order to begin at the earliest level, one must have a rationale which connects adult behavior with child behavior, and this is the point at which some of the disagreements arise. Let me summarize in brief form some of the points of view which seem to have been encountered:

1. The "content" view. This view is that the best way to learn science is to start to study physics, or biology, or chemistry, in the earliest grades. Not "how a seesaw works," but the relationship between force and energy. Not "how to feed a rabbit," but the process of metabolism. Naturally, one can't teach these scientific ideas all at once, or perhaps very rapidly in the early grades, but one can nevertheless painstakingly build up an understanding of them beginning with very simple notions and progressing gradually from these. This view has some definite merits, and no one would want to say that it is wholly infeasible. For one thing, it correctly identifies the deficiency in much elementary science teaching as being composed of isolated facts which perhaps never do get connected with a larger body of knowledge. And it is surely correct in its premise that the children are not too young to learn about science systematically, just so long as what is presented is understandable to them in terms of their previous knowledge. What is wrong with this view, then? Simply that it seems likely to run into the difficulty that the background knowledge required by the child would require a great deal of time and effort to provide.

   One can't get very far with force and energy without teaching the child how to make systematic observations, inferences, and measurements. And if one proposes to do this, the question then arises as to whether one should try to teach observation, inference, and measurement in relation to force and energy alone, or whether one ought to try to teach them with reference to animal digestion, solutions of chemicals, and so on. Having arrived at this point in thinking, one is led back to a "process" point of view after all.
2. The "creativity" view. A very different point of view is that since scientists are creative individuals, one should undertake deliberately to "train creativity." In its extreme form,

this view is that there exists a general trait in each individual which is subject to improvement through training, and which will when so developed increase the tendency of the individual to be creative in a variety of fields, including science. The kind of training needed to accomplish this, presumably, is a series of situations in which the individual practices having novel ideas and being rewarded for having them.

This point of view has some grains of truth in it, if these are properly stated. There is certainly evidence that children or adults who are rewarded for having novel ideas do tend to produce more of them (Taylor, 1964; Covington and Crutchfield, 1965). One of the neatest experimental studies of this effect that I know of showed clearly that training which encouraged children to formulate new questions, restate the problem in their own words, and generate ideas created a generalized tendency for children to do this even when they were presented with entirely new and different problems (Crutchfield and Covington, 1963). One of the most interesting findings of this study, in fact, was that this result could be obtained with training that lasted only a few hours. In a way this is disturbing to those who favor this "creativity" point of view. It is almost too easy. It doesn't really look like a general trait, but like "sensitization," as the authors of this study pointed out. Perhaps anyone can be "creative," if he is given the proper "sensitization."

Now, I do not wish to overemphasize this particular finding; more research along these lines needs to be done. What I do wish to emphasize is this: No one would think of denying that under the proper conditions, people can be "creative," and under other conditions, they cannot be. But to jump from such a fact to the idea of a generalizable trait of "creativity" which can be trained is quite unjustified. There is no current evidence which shows that one can legitimately speak of a general trait of "creativity" that is independent of other human abilities. And in making this fearful logical leap, those who speculate about it are ignoring some most important lessons of psychological research accumulated over the years. We all know that it has not yet been possible to demonstrate a single unitary trait of general intelligence, and many doubt that it ever will be. We know that many traits—which were thought to be unitary have definitely turned out not to be—honesty, introversion, conservatism, flexibility, dominance, and many others too numerous to mention. As for the effects of training, these too have tended to show themselves as rather specific changes on the whole.

3. The "process" approach. This approach seeks a middle ground between the extremes I have mentioned. At the same time, it attempts to capitalize upon the best features of both approaches. Specifically, it rejects the "content approach" idea of learning highly specific facts or principles of any particular science or set of sciences. It substitutes the notion of having children learn generalizable process skills which are behaviorally specific, but which carry the promise of broad transferability across many subject matters. The process approach also rejects the notion of a highly generalizable "creative ability" as a unitary trait. Instead, it adopts the idea that novel thought can be encouraged in relation to each of the processes of science—observation, inference, communication, measurement, and so on. The point of view is that if transferable intellectual processes are to be developed in the child for application to continued learning in sciences, these intellectual skills must be separately identified, and learned, and otherwise nurtured in a highly systematic manner. It is not enough to be creative "in general"—one must learn to carry out critical and disciplined thinking in connection with each of the processes of of science. One must learn to be thoughtful and inventive about observing, and about predicting, and about manipulating space and time, as well as about generating novel hypotheses.

Key Ideas of the Process Approach

And so we come to the process approach itself. Its basic premises may be stated as follows:

1. The scientists' behaviors in pursuing science constitute a highly complex set of intellectual activities which are, however, analyzable into simpler activities.
2. These intellectual activities (processes) are, as most scientists would agree, highly generalizable across scientific disciplines. It is not difficult for a physicist to become a biochemist, or vice versa, so long as language and techniques are learned. It is not even difficult for a meteorologist to become a psychologist—predicting the weather and human behavior may have comparable degrees of uncertainty.
3. These intellectual activities of scientists may be learned, and it is reasonable to begin with the simplest ones and build the more complex activities out of them, since this seems to be in fact the way they are organized.
4. Accordingly, one can construct a reasonable sequence of instruction which aims to have children acquire process skills, beginning with simple kinds of observation, and building progressively through classifying, measuring, communicating, quantifying, organizing through space and time, to the making of inferences and predictions. As further building occurs, one finds it possible for students to learn how to make operational definitions, how to formulate testable hypotheses, how to carry out experiments, and how to interpret data from experiments. At this point, probably, one may well have a pretty sophisticated student on his hands.
5. At the end of such instruction, the student will not necessarily know anything which can be identified as physics, or chemistry, or biology, or geology. What will he know, then? Perhaps something like this: A scientist should be able to tell this student what he (the scientist) is studying, and the techniques he is using, and what he has found, in a relatively brief fashion, and have the student display a rather profound understanding of it immediately. Presumably, such a student will *not* have to take a course in the philosophy of science in order to display this understanding.

What does this mean the student is ready for in terms of additional science instruction? I do not feel very certain of this answer. My guess is something like this: Such a student should be able to learn any given science, in terms of its theoretical structure, in about half the time that it would otherwise require. (If this means shorter courses in specific sciences, I'm all for that.)

Obviously, one of the key ideas of the process approach is the progressive building of more complex intellectual processes from simpler ones. This is in fact one of the more fascinating central hypotheses of the whole approach. I recommend that you carefully examine the hierarchy chart for the basic processes. The hierarchy chart illustrates this building process. The chart contains a separate hierarchy for each process except Communicating and Predicting, which are combined. Relationships among the process hierarchies are also shown. We do not know that the chart represents ideal progressions—in fact, we doubt that this is so. But the process hierarchies are sensible progressions, and this is probably the important thing.

Reading About Science

The sixth grader who has learned science processes in this manner should be capable of studying science in junior high school in a way in which he is not now capable. This raises the interesting question of what kind of science should he take in junior high? But there is still another difference in this "new young man" of science, which seems at least equally important. This pertains to his *reading* about science, which I believe he will wish to do to a greater extent than ever. Reading about science and scientists is important, because this is the *general* part of his scientific

education—the part that will make him scientifically literate, and also a good citizen about science, even if he doesn't ever become a scientist.

Now there are some very good books about science which are written at the vocabulary level of the fifth- and sixth-grader. But, generally speaking, they have been written under the assumption that these students know very little of the processes of science. Consequently they are likely to go to great lengths to explain something in simple terms that the student of *Science—A Process Approach* already knows about. Can you imagine a book, say, about the dating of geological strata, or about the circulation of the blood, which *assumes* that the reader does not have to be told:

1. what an operational definition is;
2. how to design an experiment;
3. how to control and manipulate variables;
4. what a hypothesis is;
5. how to interpret data?

I suspect that such a book would be a kind of "junior-level" *Scientific American*. It seems likely to me that books which are simply written, and yet which do not talk down to our "new young people" are going to be badly needed. May I urge any of you who are interested to write this kind of book?

Intellectual Skills

The experiment in which we—and particularly you—are all engaged, has a worthy purpose. It represents an attempt to establish the specific intellectual skills in students which will make it possible for them to solve problems, to make discoveries, and more generally to think critically about science from their very early years onward. I am sure most of us who have tried our hand at writing the exercises tend to keep constantly in mind the hope that these children will have science "in their bones." I believe the approach of these materials is an admirable one not only for these positive reasons, but also because it avoids the extremes which represent the "too easy" roads to success which are (1) "teach atomic theory in the first grade," on the one hand, and (2) "develop the trait of creativity," on the other.

The approach is based upon the idea that the best route to understanding and appreciation of science is by a careful and systematic building of increasingly complex human performances which include and make possible both flexible and disciplined thinking. Hopefully, this is the sort of competence which can lead, at a minimum, to a proper appreciation of science as a citizen, and at the other extreme, to the most highly original and inventive inspirations of science of which the human mind is capable.

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APPENDIX C: EXCERPTS FROM PAPERS ABOUT SCIENTIFIC INQUIRY AND THE SCIENTIFIC APPROACH TO KNOWLEDGE

The Implications of Studies of Learning*

The implications of modern psychological studies of learning and the transfer of learning are clearly to the effect that high degrees of transfer or generalizability are not produced by practice on a narrowly defined task, nor on a series of such tasks, regardless of how intensive such practice may be. Recent studies in conceptual development in children also bear out the thesis that growth of scientific concepts and logical thinking are related to a great deal more than mere practice of procedures.

In connection with these problems it is of interest to ask: What are some of the conditions of learning which can be introduced into the classroom to maximize the learning of processes and, one hopes, consequent generalizability of knowledges?

Two *main conditions of the learning situation* appear to be needed to attain such an objective:

1. Practice of the performance relevant to each newly acquired knowledge should involve the use of a wide variety of materials, in a wide variety of situations. An implication of this for developing units of instruction is that the achievement by the individual of a specific goal, understanding, or capability should be measured in terms of various kinds of performances (not merely verbal responses) and with various kinds of content.
2. The arrangement of the learning situation should be such as to insure that the overt activities required are produced from the individual's own internal processes, rather than being tied to specific stimuli provided by the teacher.

In other words, learning will be most effective when relationships are "discovered" rather than "copied," when generalizations are attained rather than being imposed.

A reasonable interpretation of various lines of thought concerning learning transfer leads to the idea that there are basic types of broadly applicable knowledges that underlie the practice and the understanding of science. They are kinds of activities that every scientist engages in, yet does not stop to think about because he knows them so well. He observes; he makes accurate and reliable

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*This excerpt and the following one are taken from a paper prepared for the first summer writing session (1963) by Robert M. Gagné and Mary Lela Sherburne, and published in the monograph, *The Psychological Bases of Science—A Process Approach,* AAAS Miscellaneous Publication 65-8.

descriptions; he classifies; he measures; he perceives relationships in space and time; he draws reasonable inferences; he experiments. These are the skills that are generalizable to all kinds of science content. The problem of designing an elementary curriculum for the early grades is one of insurin that these kinds of skills are well-learned, so that they will form a basis for the later mastery of science as a discipline.

The Basic Knowledges

The basic knowledges are those that are necessary for an individual to possess at as early an age as possible, in order to pursue seriously the study of science in the later elementary and junior high school. They are regarded as goals that will be the product of the kind and organization of instruction and units of teaching, as well as the maturation of the child.* They can be characterized in the following manner:

First, each of the basic knowledges consists of many subordinate skills and components proceeding from the simplest to those of considerable complexity.

Second, each subordinate knowledge is conceived of as building upon, and in a learning sense depending upon, all of the simple subordinate knowledges in the sequence, as well as some in other sequences. A progression of sequences has been postulated which makes for a high probability of learning the next higher unit of basic knowledge, if the student has already mastered the related ones below; and for a low probability if he has not.

Third, these basic knowledges are thought of as something that the individual either possesses or does not possess. Accordingly, each is something the individual can learn, not merely a sequence he is exposed to. It is expected that materials can be written which express in specific terms the accomplishments desired for the student in response to certain units of instruction. These goals can be expressed in terms of activity words, such as classifying, measuring, recognizing, explaining, reading, identifying, demonstrating, computing, illustrating, constructing, making, and others. Such words are to preferred to terms which are more loosely defined, such as understanding and comprehending.

Fourth, a characteristic of these basic knowledges is that they can serve as a basis of units of instruction, either singly or in combinations of two or three. It needs to be borne in mind that what is sought in any case is a wide variety of experiences and content examples within which these various knowledges can be practiced.

The eventual goals of understanding are expressed in their broadest terms; that is, knowledge of the world as science sees it, of science as an enterprise, and of scientists. The sequence of units emphasizes that, while the curriculum is built in the framework of processes, it cannot be divorced from the body of content knowledge. In the early years, the knowledge of the world, as science sees it, is small. Some of the basic skills which can be developed at this age are really tangential to science. But as the child matures and advances in level, the basic knowledges converge more and more into the content and body of knowledge known as science. At the higher grades and advanced levels the processes and contents cannot be so profitably considered apart from one another.

Although not specifically described, it is thought that a sequence of *mathematics* should be included. As conceived, such a sequence has one unique and interesting characteristic:

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*How these "knowledges," fundamental to understanding and engaging in the processes of science, would be termed was the subject of various discussions during the preparation of this paper. In one sense, as these knowledges are referred to in the stated purpose of the materials to be prepared, they are "skills" or "competencies" which enable one to use knowledge effectively. Yet they must be regarded as far more than mere technical proficiencies. In an attempt to insure that words do not reduce the teaching of science into mere methods and skills, the term "knowledges" is used to imply skill, competence, ability, and the concomitant understandings.

namely, that the particular knowledge units shown have been derived as requirements to support the other units in science. In other words, this mathematics is essential for science instruction.

The sequences in the knowledge units are not definitive but suggestive. They are descriptions for teachers and curriculum makers, and accordingly are not expressed in terms the child is expected to use. For example, where one unit describes "drawing reasonable inferences from observation," it does not mean to say that the child should describe what he is doing, or be able to make a verbal response to a question so stated. It simply means that the child should be able to perform that particular relational action, perhaps using his own words (or even no words at all, if a suitable observation of his performance can be devised which excludes them).

The Problem of Content*

The volumes of *Science—A Process Approach* cover a variety of content, from many of the scientific disciplines. Some disciplines may be given more emphasis than others, but if this is so, it was not planned that way.

The course of development of exercises emphasizing processes requires considerable discipline of thought among the scholars assembled as a design team. In particular, they need to be constantly on guard that they are not injecting their own specialized interests and enthusiasms for their own subject into the exercise being developed. The "process approach" is one which subordinates the acquiring of verbal content knowledge to the gaining of process skills. A chemist may say to himself, "It would be wonderful if these students could learn about molecular weight; then they would not have to learn it in high school." If he thinks too hard along these lines, he is likely to end up trying to teach first graders about molecular weights.

But this is not the process approach, and will not accomplish what this approach is intended for. We do *not* want to teach "first grade biology," "second grade physics," and so on, because it is believed that such knowledge is bound to be incomplete, shallow, verbally parroting, and highly ineffective for the later learning of the separate scientific disciplines. What the chemist (in our example) *should* be aiming for in designing learning exercises for the elementary grades is this: Teach the student to be so competent in the processes of science that when he ultimately learns about molecular weights he will learn rapidly, without confusion, and with a profound comprehension. He will not be disturbed by the fact that "he can't see it;" he will not tend to confuse it with atomic number; he will immediately understand its relation to molecular structure; and so on. The process approach is designed to make possible the rigorous study of science by people who don't have to be told "what science is," "what observation is," "what a hypothesis is," and all the rest of these fundamental ideas which should be valuable parts of their general education.

In any case, the problem of choosing proper content is always present in designing instructional materials for science. In looking toward the development of material for the fourth and fifth grades, it would seem desirable to make an attempt to be representative of all the scientific activities described in the previous section. But, considering the aim of getting the student ready to undertake the serious study of science as a discipline in junior high school, some attention needs to be paid to the scope and variety of exercises being designed, insofar as their content is concerned.

Since the material to be developed must *sample* content, it seems reasonable to arrive at a representative sample by listing certain *key ideas* of the various sciences. These will provide an additional framework for the student's later study of the individual sciences topic by topic,

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*This excerpt is taken from a paper prepared for the second summer writing session by Robert M. Gagné, and published in the monograph, *The Psychological Bases of Science—A Process Approach.*

and thus will be of some aid to subsequent learning. In biology a key idea might be *the diversity of living things*; in physics, *forces and interactions*; in chemistry, *the structure of matter.* Some of these will doubtless exhibit overlapping among traditional disciplines, and this is of course not undesirable.

INDEX OF TERMS AND TOPICS

As you study the exercises on the thirteen processes of science and the background papers of this *Commentary*, you may wish to refer to the exercises for children in which a topic or term is introduced or used again. This index is intended to assist you in finding the appropriate exercises. The references are to the AAAS–Xerox edition of Parts A through G. (Reference to metric units, are not intended to be complete, since they permeate the program. The first reference for a metric unit will be to that exercise in which the unit is introduced and defined.)

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